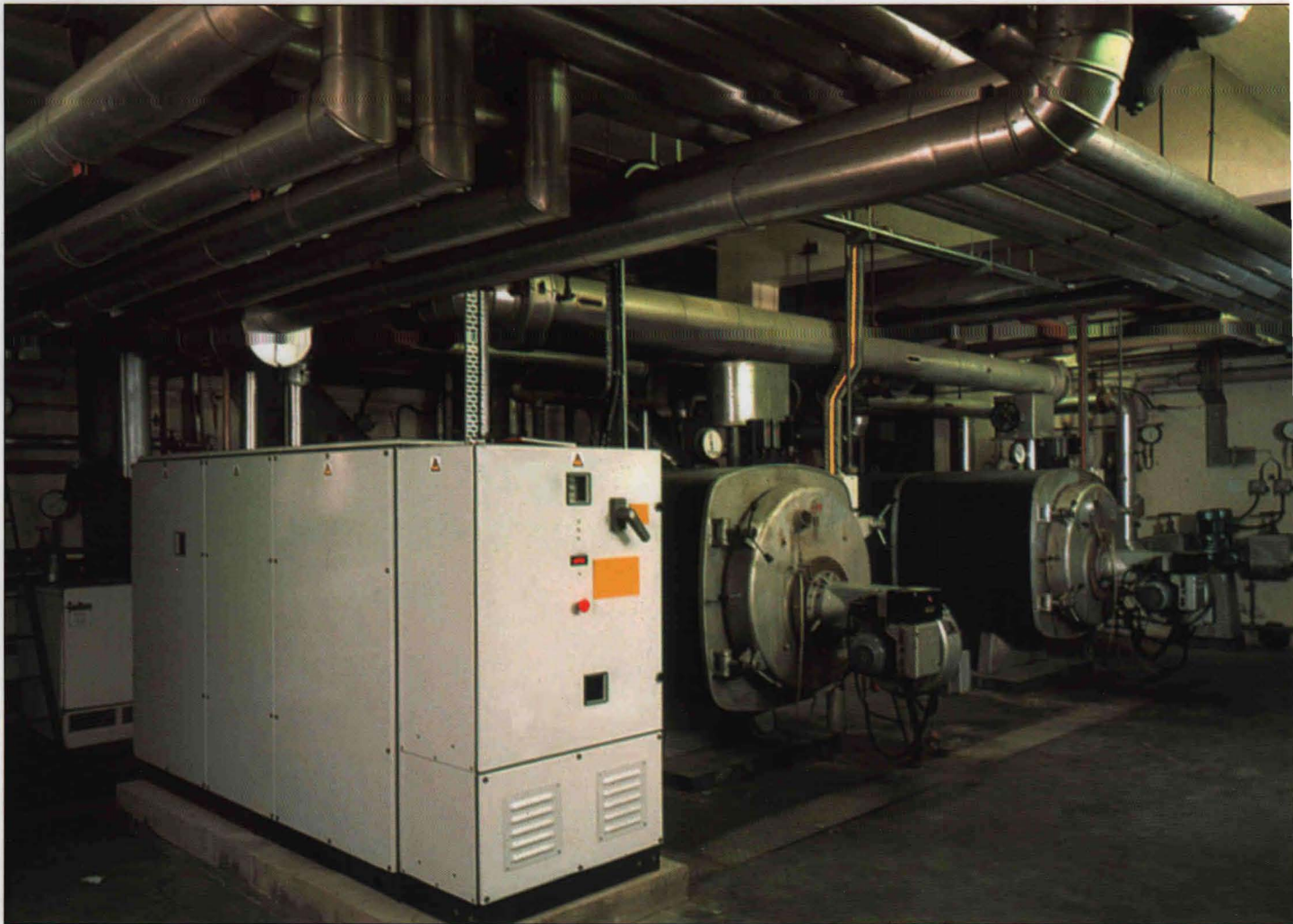


Guidance Notes for the Implementation of Small Scale Packaged Combined Heat and Power



Energy Efficiency Office
DEPARTMENT OF THE ENVIRONMENT

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Good Practice Guide

1

GUIDANCE NOTES FOR THE IMPLEMENTATION OF SMALL SCALE PACKAGED COMBINED HEAT AND POWER

This Guide forms part of an extensive range of freely available literature on CHP, prepared for the Energy Efficiency Office. The full range includes Case Study profiles, Reports and Guides, covering CHP in buildings, industry and applications using waste derived fuels.

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FOREWORD

This guide is part of a series produced by the Energy Efficiency Office under the Best Practice programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

- *energy consumption guides*: (blue) energy consumption data to enable users to establish their relative energy efficiency performance;
- *good practice guides and case studies*: (red) independent information on proven energy saving measures and techniques and what they are achieving;
- *new practice projects*: (green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;
- *future practice R&D support*: (purple) help to develop tomorrow's energy efficiency good practice measures.

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GUIDANCE NOTES FOR THE IMPLEMENTATION
OF SMALL SCALE PACKAGED
COMBINED HEAT AND POWER (CHP)

1. INTRODUCTION

CHP itself is not a 'new technology', although it has undergone radical changes in recent years as a result of renewed interest following the advent of the 1983 Energy Act. In particular several plant suppliers have assembled CHP units as complete standard packages. Such CHP is designated as 'small scale packaged CHP' and generally includes units with an electrical output not exceeding 500 *kWe**, though larger units are also sometimes supplied as a package.

With few exceptions most organisations contemplating the installation of small scale packaged CHP will be concerned with improving their energy efficiency and thereby saving money and improving profitability. However, investment in a CHP system does not in itself guarantee that significant savings will be made. Detailed attention to the specification and installation of CHP plant is necessary in order to achieve full potential for savings.

There are within the industry those who believe that, if CHP is to achieve and sustain its full market penetration and savings potential, there is a need to increase the awareness of CHP amongst those engaged in its selection and operation. Independent monitoring of a number of CHP demonstrations which have been funded in part by the EEO, has confirmed this belief and thus the need for this guide was established. Packaged CHP is now well established in the UK, with over 500 installations, representing a total installed capacity of over 50 MWe. This technology is also applied successfully in many other parts of the world.

The aim of these Guidance Notes is therefore to explain the philosophy behind a successful CHP system, and to indicate those aspects which require particularly detailed attention.

These Guidance Notes are not intended to be step-by-step instructions in the design and installation of small scale packaged CHP systems. They are intended for those people who have experience of installing mechanical and electrical equipment such as boilers, heating systems, electrical distribution networks and standby generators. A summary with a check list of actions and key points is included in each section. The first part of the Guidance Notes, Part A, is intended primarily for those who are not familiar with CHP systems. Parts B, C and D detail, respectively: CHP feasibility and economics; installation; commissioning and operation.

* Words in italics are explained in the glossary.

PART A: INTRODUCTION TO CHP SYSTEMS

2. FUNDAMENTAL COMPONENTS OF A CHP SYSTEM

A CHP unit (see Fig 1), consists of five basic components:

- An engine.
- An electricity generator.
- A heat recovery system.
- A control system.
- An exhaust system.

In some installations an acoustic enclosure is necessary to reduce noise levels.

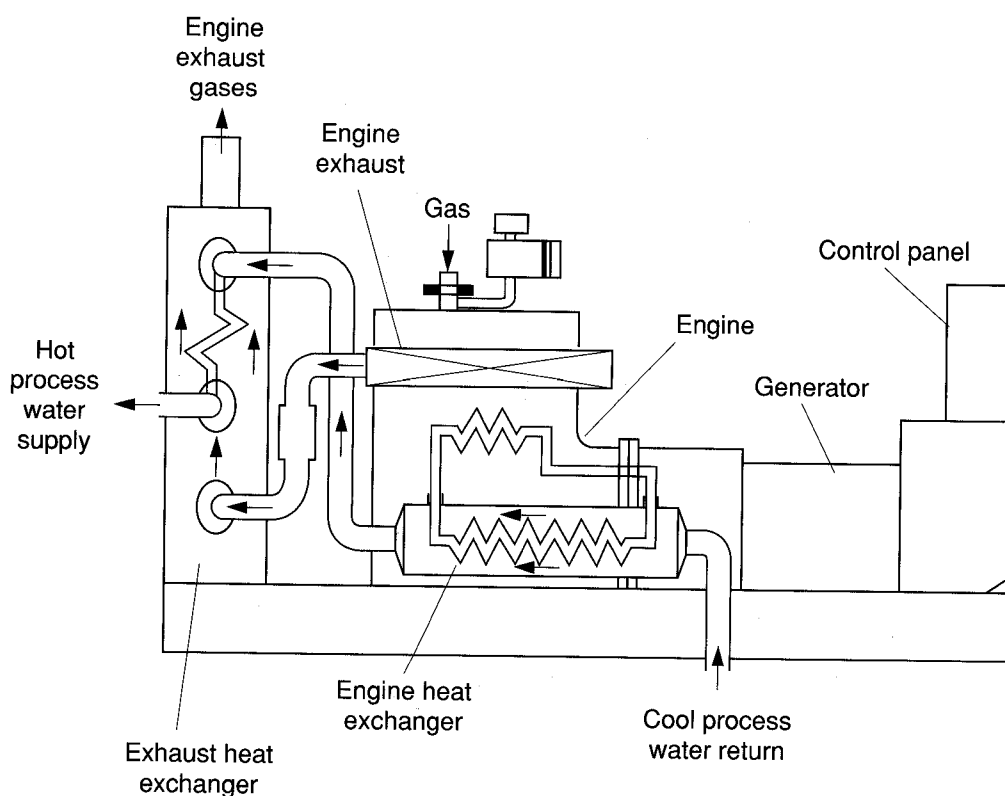


Fig 1 Typical CHP unit - its main components

Typically up to 80% (*gross CV basis*), and sometimes as much as 90% or more, of the fuel input can be usefully converted to electrical power and heat. This compares well with boiler plant energy *conversion efficiencies* but, whereas a boiler only produces heat, a CHP unit also produces high value electricity and it is this that provides the financial savings. As a guide, approximately 28% of the fuel input is converted to useful electrical power and 50% to useful heat.

The actual conversion efficiencies will depend on the particular unit, and in the larger sizes as much as 35% of the fuel input may be converted to useful electrical power. Fig 2 shows a typical heat balance for a small CHP unit.

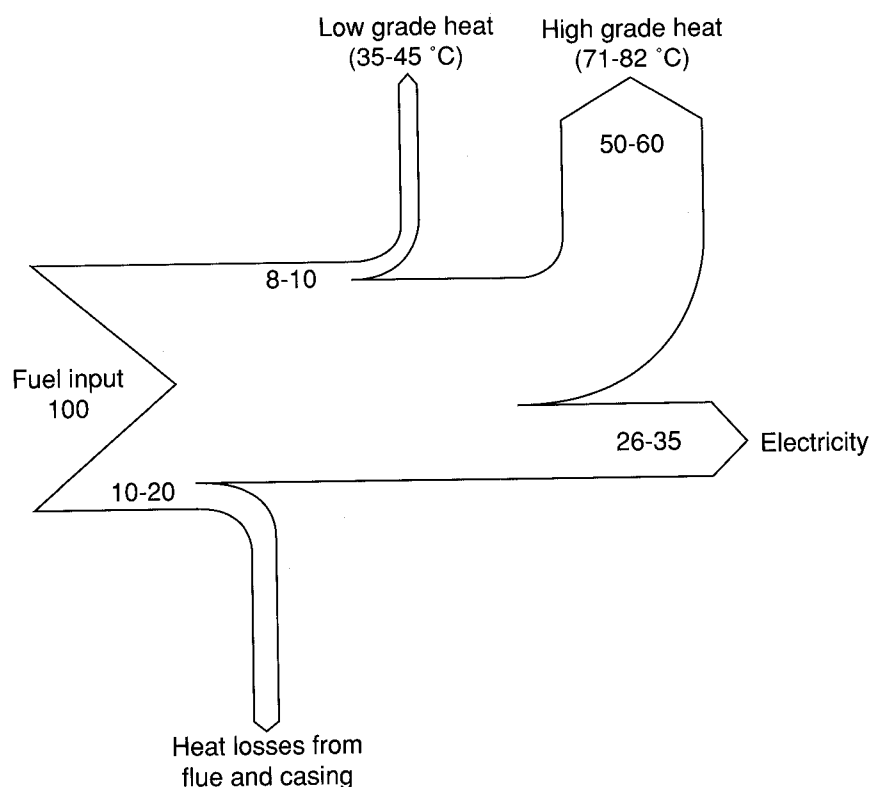


Fig.2 Energy balance of a typical reciprocating engine CHP unit

2.1 Engines

There are three main types of engine currently used in CHP systems; industrial gas engines, automotive derived gas engines, and diesels. Sizes start at about 26 kWe output.

The most popular fuel for CHP systems at the moment is gas. This is usually used in a *spark ignition* gas engine, which can be either an automotive-derivative or an industrial type.

Diesel engines are also being used in new packaged CHP systems and there are a number of existing diesel engined standby generators that have been converted for CHP use. Diesel/gas dual fuel engines are also found in large CHP systems above 500 kWe output and are thus not covered by this guide.

2.1.1 Industrial Engines

Industrial engines are heavy rugged *stationary* types that have been developed for the purpose of providing reliable power with very low maintenance costs. Like ships' engines, they are built with large bearing surface areas for low wear and are constructed for ease of maintenance. Spark ignition gas or diesel types are both available, though the former is more likely to be encountered in CHP units. Their main use has been for pumping and prime power duties where grid electricity is not available, such as in oil fields. They are extremely long-lived and require relatively little maintenance. There are many examples that have exceeded 50,000 hours running time. Industrial engines are generally used in packages with electrical outputs above 150-200 kWe.

2.1.2 Automotive Derived Engines

These are the most widely used engine types for CHP systems up to 200 kW and there is now considerable operating experience in terms of reliability and maintenance. Automotive derived engines used in CHP systems are based on de-rated and modified lorry engines, converted to run on gas. This is usually achieved by altering the pistons, cylinder heads and valve gear, to cope with the different requirements of the spark ignition or gas fuelled engine.

The engine life, as a CHP unit, when measured against that of its automotive parent, is considerably extended, as is the interval between servicing. This is achieved by running at a much slower and constant speed, typically 1,500 rpm under steady conditions.

Engine life is shorter than that of the industrial engine, generally 20,000-30,000 hours prior to a full engine overhaul, but with longer lifetime for larger units.

2.1.3 Diesel Engines/Standby Generators

The most commonly encountered diesel engines other than those in road vehicles will be those fitted to standby generator sets which have been installed to protect vital services. The fuel options will generally be limited to *gas oil*.

Although standby generators are frequently based on industrial diesel engines, the history, pedigree and condition of the actual engine under consideration should be carefully evaluated before any conversion proceeds because previous low utilisation does not necessarily imply that the engine is in peak condition. The primary considerations for CHP are not necessarily the same as for standby operation. In particular, units will generally be larger than required for optimum operations as CHP.

An important benefit to be gained from converting standby generators to CHP is that an engine used regularly and properly maintained should have a proven level of reliability and therefore invoke a higher confidence level in the event of a mains supply failure.

2.1.4 Relative Costs

When comparing industrial and automotive engines for CHP systems, it is important that the supplier has established realistic life-cycle maintenance costs as this directly affects the economic feasibility of CHP. These aspects are discussed in detail in Part B of this guide.

By virtue of their smaller production volumes, heavier construction and generally low specific outputs, industrial engines may cost more initially in capital terms than their automotive derived counterpart. They may also have a higher spares cost than auto derivative engines, but ultimately a lower consumption of spare parts.

The advantages of an automotive engine are that it is generally relatively cheap in initial cost, and spares, other than the converted items, are available as for the parent automotive engine.

The use of standby generator sets as CHP units may be attractive, as conversion to CHP may entail only the addition of heat recovery equipment and an interfacing system, so that capital costs should be lower than for a complete CHP unit. Maintenance costs are generally higher for diesel engines through increased sooting and emissions when compared with gas engines.

2.2 Generators

There are two main types of generators used in CHP systems; asynchronous and synchronous. A synchronous generator always rotates at a fixed integer multiple of the mains frequency; usually 1,000, 1,500 or 3,000 rev/min for 50 Hz mains. With an asynchronous generator the rotor speed is up to 2.5% faster and will vary with the power output. On the smaller units approximately 26-29% of engine fuel input is converted to electrical power although continuing research and development is being undertaken to increase this to 30% or more, as obtainable from some of the larger units.

2.2.1 Mains Excited Asynchronous Generators

Mains excited asynchronous generators are identical to the very common induction motor, and are thus often used to start the engine, becoming a generator when the motor has run up to

speed and the engine is able to provide the necessary power. In the smaller sizes, they are more efficient than their synchronous counterpart but care is required to limit starting currents when used to crank the engine. Because they are normally connected to the mains in order to provide the *excitation current* which supplies the operating magnetic field, they cannot readily be used as a standby generator without modification. Also, because of the requirement for mains excitation, the power factor is always less than unity which may incur charges for reactive power taken from the grid. However, the careful selection and use of power factor correction capacitors can minimise these charges. Asynchronous CHP generators are available in sizes from 26 kWe to over 500 kWe.

2.2.2 Synchronous Generators

The synchronous generator has a more complex system than the asynchronous unit as it must maintain its own frequency standard and requires equipment to enable synchronisation with the mains. Synchronous units have the advantage of being fully able to double as standby generators and do not require power factor correction. In the past they have been used to control power factor. The output power can also be readily controlled or 'modulated' over a wide range. They are generally available in sizes from 32 kWe upwards.

2.2.3 Relative Costs

Synchronous generators with outputs below 100 kWe tend to be more expensive than their asynchronous counterparts. The additional equipment needed to start the engine, control the generator and interface it with the mains can add to the cost of smaller CHP units. This may not be justified unless there are real benefits from the provision of a standby facility. In general above 100 kWe output the cost advantages of asynchronous over synchronous types disappear.

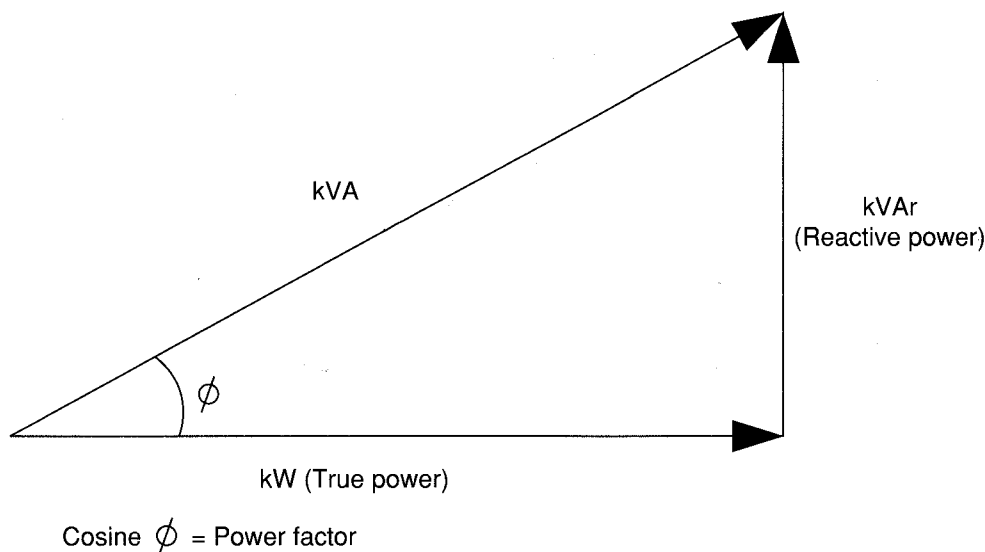


Fig 3 kW, kVA and kVAR relationship

2.2.4 Output, Power Factor and kVA

The power output of a generator is stated in kilovolt-amperes (kVA) and is obtained from the measured resultant voltage at the generator's terminals and the measured output current. If the voltage is exactly in phase with the current produced, then this is all 'real' useful electrical power and equal to the generator output in kilowatts (kWe) of electricity.

In practice, because the field windings which supply the magnetic field to the generator take current 90 degrees out of phase with the voltage, the kVA output and the kWe output are not the same. The power factor is the ratio between the two and is usually shown as the cosine of the phase angle between voltage and current (see Fig 3).

The out-of-phase reactive current which dissipates in part as heat in connecting wires but transmits no useful power is expressed as VAR (Volt-Amps reactive) or kVAR.

Regional Electricity Companies (RECs) may levy additional charges on customers with poor power factors because of the extra losses incurred in supplying energy. Consumers should therefore endeavour to keep power factors as near to unity as possible and so keep their own losses and cable sizes down to a minimum. CHP controls can regulate power factor, within certain limits. Further advice should be obtained from equipment suppliers.

2.3 Heat Recovery Systems

Generally, in a CHP system, in order to obtain maximum savings, it is essential to recover as much heat as possible from generator, engine cooling circuits and exhaust gases, and to feed this into the building heating or domestic hot water (DHW) system, so reducing the amount of heat needed from the normal heat-only boiler. Over 90% of the available heat can be recovered, but to achieve this requires the use of several heat exchangers. Typically, around 50% of the fuel input is recoverable as useful high grade heat in the form of low temperature hot water (LTHW). A further 10% or more can be recovered as low grade heat at 30-40 °C. This compares with around 75-80% for a boiler operating at full load.

The source temperatures and range of recoverable heat are shown in Table 1.

Table 1 Recoverable heat from CHP engines

Source	Temperature °C	Recoverable Heat % Fuel Input
Engine Jacket	120	33
Exhaust	650	22
Exhaust <i>Latent Heat</i>	70	10

The source temperature limits the form of the recovered heat. Approximately 33% of the fuel input can be recovered from the engine jacket cooling in the form of LTHW at 70-85 °C or steam at up to 15 psi, using *ebullient cooling*. Steam at 100 psi can be recovered from the exhaust gases also using ebullient cooling but the heat recovery efficiency is reduced compared with conventional LTHW heat recovery. Equipment costs are also higher.

Through condensing heat recovery the latent heat can be recovered from the exhaust gases in the form of hot water at 30-40 °C.

2.3.1 Water-to-Water Heat Exchangers

Over 60% of the high grade heat available is in the engine cooling jacket, but for reasons of pressure, corrosion and thermal shock, this cannot generally be connected directly into the building services water, and so the heat is normally transferred by means of a water-to-water heat exchanger.

The most common type in use is the '*shell and tube*' heat exchanger, many of which are physically quite long and will therefore require good access for complete removal for maintenance purposes.

2.3.2 Gas-to-Water Heat Exchangers

The heat in the exhaust gases is recovered by passing the gases through a gas-to-water heat exchanger. This can carry building services water direct and accordingly lends itself to higher temperatures if required. An alternative is to link this heat exchanger into the engine jacket

circuit which is very convenient on packaged CHP units as it limits the site work but has the disadvantage in that it may restrict the temperature range of the unit.

It is very much the preference of the manufacturer as to which way and how the heat exchangers are connected, there being advantages in either approach. The exhaust heat exchanger may be bypassed on the gas side if necessary in order to facilitate the use of the CHP unit in summer when heat requirements are reduced or when the CHP unit is required to operate in standby emergency mode. In the latter case means must also be provided for dissipating the heat from the engine cooling circuits if there is insufficient capacity in the site heating system.

2.3.3 Condensing Heat Exchangers

The gas-to-water heat exchanger, as normally fitted to a CHP system, reduces the exhaust gas from about 650 °C to about 120 °C. Some manufacturers offer an additional condensing heat exchanger which can recover even more heat by condensing out the water vapour in the exhaust gases, and thus gaining a proportion of the latent heat of evaporation thereby improving thermal efficiency. Condensing of the exhaust gas will occur at around 55-60 °C, depending on the fuel gas-to-air ratio. This exchanger is usually connected directly to a source of cold water typically at less than 40 °C, such as DHW cold feed, swimming pool or boiler make-up water, and is hydraulically entirely separate from the rest of the CHP system. Special care is necessary when including such circuits.

Condensing heat recovery is usually only applied to units burning natural gas. Diesel or biogas exhausts contain higher levels of sulphur dioxide and other waste products, which may severely corrode the exhaust fittings if condensed out with the water vapour.

2.4 CHP Unit Control Panel

The function of the CHP control panel is to control the start-up and shut-down sequence of the unit as well as monitoring the mechanical and electrical conditions during normal running. Control systems range in sophistication from relay logic and solid state systems to full micro-processor control with remote condition monitoring.

The actual start-up sequence will depend on the manufacturer and the degree of sophistication offered; some units providing pre-circulation of oil and battery starting with full system proving before on-load operation.

On shut-down, all units must be disconnected from the mains and fuel supplies cut off, but the water pumps may continue to operate until the engine block has cooled sufficiently. Again the exact sequence of events depends on the CHP system designer's preference, and the size of unit.

2.4.1 CHP Unit Monitoring

Whilst running, the control system monitors the various sensors that will cause shut-down. On a typical gas fuelled engine these may include:

- interlocks with heating system pumps;
- flow switches in pipework;
- control and limit thermostats;
- low engine oil pressure;
- emergency over-temperature thermostats;
- low gas pressure;

- high gas pressure;
- overspeed sensor;
- low speed protection;
- electrical power overload.

When any of these parameters go outside preset limits, the system will generally shut down, activate a visual alarm and not restart until manually reset. This is termed a 'lock-out'. Some units may attempt one or more re-starts before lock-out occurs, either after a time interval or when the condition has cleared.

2.4.2 Electrical Mains Safety Monitoring G59/1*

The controls must maintain compliance with the Electricity Association Engineering Recommendation G59/1, which sets out the conditions to be met by a generator when connected to the grid. The requirements are considered in more detail in Part C of this document.

The main stipulations are that the unit must be isolated from the grid within 0.5 secs. under the following conditions:

- in the event of failure of one or more phases in the distribution network;
- if the difference in the declared supply voltage (usually 415V AC) and the generator output exceeds +10% or -10%;
- if the frequency of the generator departs from 50 Hz by +1% or -4%;
- in the event of failure of the REC's supply.

G59/1 also stipulates that the control equipment must be fitted with an auto-trip or alarm that will indicate if the power supply to the controls fails. This is to ensure that the equipment is fail-safe.

2.5 Exhaust Systems

In common with boilers, CHP units require an exhaust system to carry away the products of combustion which may contain small quantities of carbon monoxide and other noxious gases.

These gases are to some extent corrosive and therefore suitable materials must be used, condensate drains may also be required. In most instances a silencer will be required to attenuate the noise from the engine.

For these reasons the exhaust should terminate away from people and windows, etc.

2.6 Acoustic Enclosure

In many cases the noise created by CHP units is quite acceptable without any system noise containment being necessary. However, where particularly quiet operation is required, an acoustic enclosure can be fitted: it is then not uncommon to find that the CHP unit is quieter than the adjacent gas boilers. Most packaged units are provided with acoustic covers as standard; these are of steel or glass fibre construction, lined with special sound-deadening material and are fitted with air intake silencers with appropriate ventilation to dissipate heat from the engine and generator.

* The existing Recommendation G59 is still in force at the time of going to print (2/93).

KEY POINTS

- CHP engine types include stationary, automotive derived and standby diesel generator conversions.
- It is essential to establish realistic life-cycle costs for the system based on true maintenance requirements and engine lifetime.
- Above 100 kW_e output, synchronous generators are preferred on a cost basis. Otherwise the choice between asynchronous and synchronous generators depends on the requirement for a standby facility and on package specification.
- Separate heat exchangers are used for heating by recovery of the high grade heat in engine jacket cooling water and exhaust gases. Other options include: low grade heat recovery from the latent heat in the exhaust gases; steam generation, at reduced heat recovery efficiency, using ebullient cooling; a combination of these methods.
- Control systems must meet the REC requirements and can range in sophistication from relay logic and solid state systems to full micro-processor control, generally with remote condition monitoring.
- A properly designed exhaust system is required to carry away the products of combustion.
- An acoustic enclosure is generally fitted as standard to provide quiet operation.

3. CHP/BUILDING SERVICES' INTERFACE

Normally CHP does not operate in isolation; it has to interface with the building heating and electrical services and, in the case of the former, the CHP must also interface with the control system. In this section the basic requirements for CHP installation are outlined. Detailed information will be found in Part C of this guide.

3.1 Heating System

CHP is generally only suitable for low temperature hot water (LTHW) heating applications which means that in practical terms, temperatures into the CHP heat recovery circuits are limited to between 70-80 °C although specially adapted units may permit operation at temperatures up to 125 °C. If steam or high temperature hot water (HTHW) is the heating medium, as is frequently the case in hospitals and on industrial sites, then an application will generally have to be found at a local level where there is a steam-to-LTHW calorifier already in use. This is frequently the situation with radiators and DHW systems.

To maximise CHP running hours (and hence savings), a year round heat demand is preferable, though it need not necessarily be for 24 hours per day. However in practice, it is unlikely that units operating for less than 3,000 h/year will be cost effective unless tariffs and fuel prices are particularly favourable.

Connection can be in series in a suitable return water feed to the boilers, in parallel connected between the main system flow and return headers, or a combination of both depending on the number and size of units ultimately selected.

Water volume flow requirements of CHP units may differ considerably from those of the heating system and must be assured whenever the CHP unit operates.

3.2 CHP/Heating System Controls

For satisfactory operation there must be a suitable method of controlling both the operation of the boilers or other heat sources and the operation of the CHP system.

This may require the provision of an integrated control system which will ensure that:

- the CHP system supplies the maximum feasible quantity of heat, and the boiler(s) the minimum;
- the temperature of the water fed into the CHP system is acceptable, generally at or below 70 °C;
- hot water storage facilities are utilised to the maximum benefit;
- the appropriate number of CHP units are brought into operation to meet the base heat load, with top-up supplied by the boilers.

Methods used may vary from a simple thermostat acting on the return water temperature, to a sequence and temperature control from a *Building Energy Management System* (BEMS). Correct design of the control system and interfacing of the CHP units into the heating system will ensure the maximum operating hours for the CHP plant.

If the unit is required to operate in emergency generating mode there may be a requirement to provide heat dumping facilities where the heating system capacity is insufficient to ensure that the unit can run when required.

3.3 Electrical Services

Generators are usually wound for 415 V operation and connected to the medium voltage service. Providing the CHP electrical output is relatively small in relation to the total site demand, this generally presents the least difficult connection to achieve.

If standby duty is required of the CHP generator, a system must be provided for disconnecting non-essential load in stand-alone mode. To achieve this may require a compromise in essential load definition, considerable site wiring changes, or multiple automatic switches. In addition, auto-mains isolation and manual lockable isolation will be required by the electricity supply authority.

3.4 Part-Loading, Modulation and Cycling

Unlike a boiler, repeated cycling will rapidly shorten the life of a CHP unit since a large amount of wear takes place in the first few minutes of operation, especially when the engine and lubricating oil is cold. Accordingly, some manufacturers minimise such effects by pre-pressurisation and/or heating of the lubrication system before start-up. Avoidance of repeated cycling will come from correct sizing, and by the correct application controls. Most units will include a timer which will limit the number of starts to perhaps six or eight per hour.

Operating CHP units at less than their full power output, either by modulating the output or cycling, will reduce the overall efficiency. Manufacturers' ratings are based on continuous steady state conditions and do not take into account the energy used in starting the unit, or the effects of warming up to achieve the steady condition.

Maintenance costs are usually calculated on an hours-run basis. As long as the engine is turning, it is wearing out. If the output is modulated down, the maintenance costs per unit of electricity produced will increase and may make operation uneconomic, especially at times of marginal benefit. In addition, under sustained cycling, maintenance requirements will actually increase and reliability will fall due to the extra demands imposed on the equipment.

If the CHP system is to be used for standby generation, and its size increased accordingly as is generally so, it may be more economical to install two or more smaller units. In CHP mode these can be sequenced in and out of operation as required, and so ensure that they are run at full output. There will, however, be a reduction in hours run for individual units, ultimately affecting the economic viability of the scheme unless some notional benefit can be credited to the savings due to their use as standby generators.

KEY POINTS

- CHP is generally suitable only for LTHW heating/DHW systems but can be used on steam or HTHW heated sites where there is a suitable calorifier.
- The CHP unit and the heating plant must be properly controlled.
- For standby operation the essential circuits should be carefully assessed to ensure that the CHP system is not overloaded in stand-alone mode.
- The CHP unit should preferably be operated at full load to prevent excessive wear and ensure maximum operating efficiency.

PART B: CHP FEASIBILITY AND COST SAVINGS

4. SITE APPRAISAL

In order to assess the suitability of a site for CHP it is necessary to check a number of separate factors. This should be undertaken in stages as ultimately the final decision as to what plant to install will involve obtaining some detailed information and, unless the initial findings are encouraging, the effect entailed may not be warranted.

An important factor in sizing CHP systems is the heat demand of the building and/or its services. To achieve a simple payback of 3-4 years, a CHP unit generally must operate for 4,500-6,000 hours/year, though less where fuel costs and generation patterns are especially advantageous. In particular, for the shortest payback, there should be a worthwhile year-round demand for heat, though this will depend to some extent on the electricity tariffs available.

In new buildings or those undergoing refurbishment, CHP may be particularly attractive as an opportunity to displace other systems such as boilers, vapour compression chiller plant or standby generators. In these cases the costs associated with such equipment may be offset against the CHP system thereby increasing overall cost effectiveness.

4.0.1 *CHP Applications*

Small-scale packaged CHP is being installed in many diverse types of buildings as well as in some industrial applications. There are in excess of 500 installations to date (1992) and the majority of applications are installed at:

- leisure centres and swimming pools;
- hotels;
- hospitals;
- residential establishments;
- commercial and public buildings with extended operating hours;
- sewage plants;
- industrial processes with a consistently high hot water demand.

For maximum savings and minimum payback period, the CHP unit should be both sized and controlled so as to ensure, if possible, that by running continuously it can supply the same amount of heat as the normal boiler would do by running intermittently. This may mean that it is sized so as to give a heat output close to the average summer demand. By contrast, boilers are normally sized for peak winter demand plus some warm-up allowance. It may well be economic to size a unit for a base load operation in winter when electricity prices are at their highest which is the practice most commonly adopted. Alternatively, but less commonly, a number of smaller units could be used for load matching.

For small scale installations, it is not generally economic at the present time to consider exporting electricity. This situation may change as the franchise limits on supplying electricity are reduced from the present limit of 1 MW to 100 kW in April 1994 and eventually abolished altogether in April 1998 (see also Section 6). The CHP plant should therefore be sized so as not to exceed the base electrical load for the site.

The sizing of a based-load CHP system in an existing building can be carried out from a knowledge of previous years' fuel bills, especially those for summer, together with detailed daily heat usage profiles. For new buildings, use fuel bills of similar existing buildings to check against theoretical estimates, but treat this with caution and ensure a valid comparison. Consumption data collected in a particular year will not necessarily reflect the site demand in future years and preferably calculation to a common degree day basis should be performed.

Sizing and evaluating larger and more comprehensive systems will correspondingly be more complex. This will require a thorough knowledge of the building's hourly profile of electricity and heat usage throughout the day as well as the prevailing electricity tariffs. The only way to establish thermal and electricity profiles accurately is to measure them. Obviously this cannot be done for a building not yet built so more care will be needed in such instances. If in any doubt, err on the side of caution and undersize the CHP system.

Where a unit is to be used for standby generation, its size will be influenced by the intended maximum peak emergency electrical load. For normal use its output may be modulated down to match the available heat load but the consequent reduction in efficiency on a single CHP unit may prove to be unacceptable. In such circumstances two smaller units may be more economical or both a CHP unit and a standby generator installed or the actual emergency load will have to be reduced to match the available heat load.

	YES/NO
● Is there a suitable fuel supply?
● Is there a demand for hot water throughout the year?
● Is the space heating provided by low temperature hot water?
● Is there a swimming pool or other low grade heat sink on the site?
● Is the existing boiler plant required to be on-line for more than 3,000 hours/year?
● Are fuel and electricity consumption records available on a monthly basis?
● Is the present annual thermal fuel consumption (after deducting an allowance for catering, if appropriate) more than 20,000 therms/year equivalent?
● Is the present annual thermal fuel consumption (after deducting an allowance for catering, if appropriate) more than 750 therms/month equivalent?
● Does the annual electricity consumption exceed 200,000 kWh/year?
● Does the monthly electricity consumption always exceed 8,000 kWh?
● Is the lowest monthly Maximum Demand (from bills) greater than 25 kVA?
● Is a simple payback of more than 2.5 years acceptable?
● Do site monitoring facilities exist?
● Is there suitable access and space for a CHP unit?
● Can the heating system be properly controlled by the existing heating controls?

4.1 Stage 1: Basic Assessment

As an initial step in order to establish whether a site should be considered for CHP, the following check-list may be useful. It is not essential to the viability of CHP that all the questions are answered in the affirmative.

4.1.1 First Approximation of Size and Cost

For a first estimate of the size, cost and savings benefits the following guidelines can be used for non-standby, gas-fuelled units in typical hospital, hotel or institutional installations. More accurate figures can be obtained by carrying out detailed calculations and appraisals, as discussed in Section 4.3.

4.1.2 Size of Unit

The electrical capacity of the unit (kWe) to be installed will probably lie in the range:

FROM: 1/40 (2.5%) of the average summer months' gas consumption
(excluding catering) when stated in therms.

TO: 1/400 (0.25%) of the monthly average for the lowest three months electricity
consumption when stated in kWh.

The lower of these two figures will probably emerge as the one determined by the gas consumption and whichever is the lower will usually give the shortest payback time.

If the metered maximum demand for the months with the lowest electricity use is less than 1.5 times the electrical output of the machine, then export is possible and appropriate metering is likely to be required.

4.1.3 Savings Potential

To calculate the approximate potential savings in £/year at 1992 prices, the CHP unit's electrical output (kWe) should be multiplied by 160 e.g. a 100 kWe unit will save typically

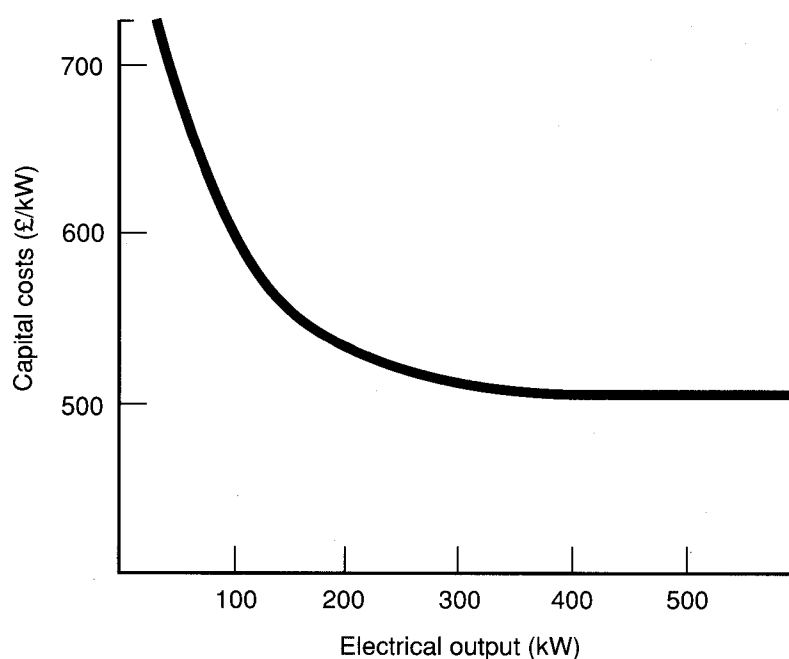


Fig 4 Installed capital costs as a function of size for gas fired spark ignition units

about £16,000/year. This is based on 5,000 hours/year of operation. Actual savings will be dependent on energy costs which will vary from site to site.

4.1.4 Installed Capital Cost

Fig 4 shows a typical spread of unit capital costs as a function of size, showing how the cost per kWe rises steeply as the size of the unit decreases. A 100 kWe unit therefore has an installed cost of approximately £60,000 (1992 prices).

4.1.5 Simple Payback Time

Simple payback is installed capital cost divided by savings. It will be obvious that the aforementioned assessment will have an implicit payback time of 3.75 years based on 5,000 hours operation. This is typical for a retrofit installation in an existing plant room. If the CHP plant is part of a new installation, savings can be made by offsetting the savings resulting from reducing the boiler capacity requirement.

4.1.6 The Next Step

If the initial assessment suggests that it is worth proceeding further then rather more detailed investigatory work will have to be undertaken and resources allocated. Whether this work is undertaken in consultation with equipment suppliers or consultants is a matter of choice depending on financial and human resource availability. Either way it is appropriate to establish:

- How committed is management to reducing costs?
- Is the necessary capital available?
- Alternatively are the terms of the leasing/finance package acceptable?
- Is the probable payback (more than 2.5 years) acceptable?
- Are there other benefits beyond simple monetary savings?
- Are there other opportunities for savings offering better paybacks?
- Are there adequate resources available to complete the investigation in the required detail?

Assuming the answers to these questions are acceptable, a more detailed study can be undertaken and the precise benefits determined for each option relevant to the site.

4.2 Stage 2: Detailed Site Appraisal

It cannot be too highly stressed that to install CHP on a site where the relevant services are not performing effectively without first remedying those faults is very likely to result in disappointing levels of savings, and in extreme cases may mean that the basis of assessment is quite wrong. For example, uncontrolled heating plant and/or unlagged pipes will increase the apparent load available to the CHP such that its size may be incorrectly determined. Accordingly the building and its services should first be examined for effectiveness without regard to the intended CHP installation.

Most CHP manufacturers will evaluate the cost savings for a project through an assessment of fuel consumption and electrical demand in conjunction with a brief site survey. As part of the site survey an assessment should be made of any aspects likely to give rise to difficulties. However it is for the prospective CHP beneficiary to decide whether the major aspects of the particular site under consideration have been sufficiently assessed and how the further evaluation of CHP is to proceed.

4.2.1 Resource Requirements

The time required to carry out the assessment is a function of the size of the site and its complexity. An experienced person should complete the work within 1-2 days for a small site, but may require several weeks on a large industrial site. An assessment properly undertaken will pay off handsomely if CHP is eventually installed and should prevent a bad investment if the site is unsuited to CHP.

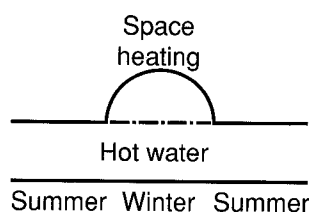
4.2.2 Effects of Heat Demand

The majority of sites for which CHP is considered will have a substantial year-round demand for heat, usually for domestic water heating or process water heating, plus a winter demand for space heating.

Ideally the CHP unit should be able to supply all of the summer load and a proportion of the winter load. Although the unit may be relatively small, generally with a heat output of $\frac{1}{12}$ - $\frac{1}{3}$ of the installed boiler output capacity, it may supply 60-90% of the building's annual heat demand. This may require additional hot water storage to smooth out peaks in demand, allowing the CHP unit to run up to 10 hours/day in summer and 17 to 24 hours/day in winter (see Fig 5), depending on whether the unit is sized for DHW alone or DHW and some space heating. Either way with a common boiler system, the boilers, which are usually sized to cope with the worst winter weather plus warm-up allowances, will supply the remainder of the heat.

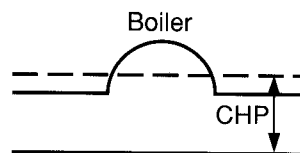
1. BOILER SYSTEM

A normal building will require heat for hot water and space heating.



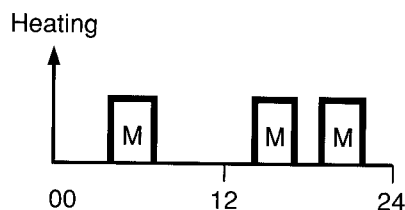
2. CHP & BOILER SYSTEM

For preference-CHP systems should be able to supply all of the hot water demand plus a fraction of the space heating.



IN SUMMER:

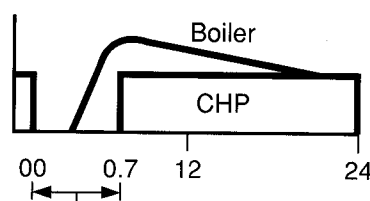
The CHP system may run for up to 10 hr/day.



The CHP cycles (or modulates) to meet the reduced base load.

IN WINTER:

The CHP is likely to run for 17 to 24 hr/day with boiler providing top up heat.



At night it may be cheaper to buy in off-peak electricity.

Fig 5 Building heat demand profiles

Assessment of the optimum size CHP unit is critically dependent on establishing what the alternative base loads are. Too large a unit and it will cycle resulting in loss of savings, premature wear and reduced reliability. Too small a unit and a savings opportunity will be lost. If in doubt, analyse the loads more carefully and then select a smaller unit rather than a larger unit: a second unit can always be added later.

4.2.3 Meter Readings and Consumption Profiles

Initially, a meter reading programme should be set in motion to gain as much information as possible on energy flows. In order to obtain more detailed profiles, the meters should be read hourly over at least a day or two of low load. If necessary, additional instrumentation should be utilised to obtain electrical profiles, using a *Demand Profile Recorder (DPR)*, and boiler operation profiles using an *event recorder*. The latter, in conjunction with fuel meter readings and flue gas sample analysis, should provide sufficient information to determine consumption profiles and boiler efficiency.

The use of CHP can substantially eliminate the operation of one or more boilers in a multi-boiler installation. Unless boilers can be hydraulically isolated, this will affect the boiler load factor and the overall boiler plant efficiency will fall.

It is essential to characterise the building and obtain at least twelve months fossil fuel and electricity bills from which the daily and hourly load profiles may be estimated, in conjunction with the meter reading programme. The bills should be examined to establish the date of the readings and hence the time interval (number of days) between successive readings. This is especially important over the summer 'low' period when year-round operation of the CHP is envisaged.

The hours of use of the heating or DHW plant over the corresponding billing period should be determined so that the average hourly demand over the day can be assessed. Be sure to make an allowance for 'other use' of gas such as catering or process use.

4.2.4 Temperature Measurement

Using a surface thermometer, measure flow and return temperatures in each of the different main hot water circuits. Observe the effect on these of the boiler firing and similarly, over short periods, the effect of both heavy and low heat demands, the objective being to ascertain from the variation in temperatures what conditions could affect operation of the CHP system. The higher the temperatures encountered, the more significant the probable effect on the CHP. Knowledge of the system and experience will show if such high temperatures are actually required or whether the control settings are unnecessarily high.

With the limited metering facilities usually encountered, it will be exceptional to be able to check actual water flow rates in heating systems, but nonetheless an attempt should be made to establish minimum and maximum rates, as this will affect the interfacing arrangements finally adopted when the CHP unit is installed. This can be accomplished in part at least by reference to manufacturers' pump curves and by observation of pump head loss under the different conditions, assuming pressure gauges are fitted.

These findings may well result in the need to make changes to the system in order to remedy existing defects prior to the installation of CHP.

4.2.5 Heating and DHW Services Investigation

If there are any difficulties with the operation of the existing heating and DHW services these should be corrected before proceeding with CHP. CHP delivers energy at a lower cost; it does not correct for poor design or misuse of the existing services or their controls.

Investigate the heating and DHW services to find out how they operate. Establish what

shortcomings exist so that these are not eventually blamed on the CHP system. Check that motorised valves operate properly and that motorised shut-off isolating valves do close. Check that timeclocks etc. are functioning properly.

To assist in ascertaining the best way of interfacing the CHP with the heating system, it will also be advantageous to establish:

- a schematic drawing of the system;
- whether the DHW and space heating systems are supplied from common boiler plant;
- whether the DHW calorifiers are fitted with diverter valves which will spill hot (flow temperature) water into 'cool' return and so shut down the CHP unit;
- if the system is weather compensated, and if so, is it by variable temperature from the boiler or via a mixing valve which in consequence reduces the return volume to the boiler plant?
- if operation of the boilers is sequenced, and if so, is the temperature controlled on flow return?
- whether the whole system, or a part of it, is under the control of a Building Energy Management System (BEMS)?
- a Sankey diagram or heat balance for the site;
- a schedule of pumps and circuit water flows and pressure losses.

4.2.6 *Typical Boiler Efficiencies*

It is important to establish accurately the efficiency of the installed boiler plant, for not only does this affect the CHP system size but it also affects the value of heat produced and the true savings achieved.

The efficiency pertinent to operation with CHP plant must be used. This is neither the full load thermal efficiency nor the seasonal efficiency of the boiler plant, but rather the efficiency related to actual loading when used in conjunction with the CHP system.

Typical modern boiler efficiencies (on a gross calorific value basis) which should be used to establish the useful heat are shown in Table 2. These efficiencies represent the incremental 'delivered heat' efficiency of heating plant which will remain on-line after the installation of CHP and with no significant change in operational practice.

Table 2 Typical Boiler Efficiencies with CHP Operation

Boiler Type	Efficiency %
Condensing boiler	85 - 90
High efficiency modular boiler	80
Packaged hot water 'shell' boiler	78
LTHW modular boiler	76
Indirect steam raising packaged shell boiler	73
Cast iron sectional boiler	71
Unknown boiler type	75

A boiler which can be wholly shut down following the CHP installation will accrue additional savings and conversely a large boiler left 'ticking over' will perform adversely, reducing savings.

With the above information, annual, daily and possibly even hourly profiles of useful heat can be determined. When the CHP system is sized for base load operation, it will usually substitute only in part for the total heat load.

4.2.7 Utility Suppliers

Discussions with the gas and electricity suppliers should not be overlooked, as this may affect the installation and operation of the CHP unit. There is a statutory obligation to inform both the gas supplier and the REC when installing CHP.

It is advisable to consult the gas supplier as to whether the gas supplies are adequate. In an existing building the CHP unit will be acting in substitution for the boiler plant, and the increase in consumption due to lower thermal efficiency of the CHP unit will not be significant. For new buildings, gas supplies are negotiated in the usual manner. If low gas pressure problems are thought likely, a gas booster facility should be used.

The local REC should be consulted to determine their requirements (if any) for special protection equipment, larger cable sizes or changes in the metering and tariff arrangements.

KEY POINTS

- An initial assessment for CHP suitability should be carried out based on analysis of the site electrical and heat demand. It is generally most economical to size a unit for base load operation.
- A more detailed assessment should include an appraisal of the operation of the site services to establish interfacing requirements with CHP system. Detailed daily consumption profiles should also be obtained.
- Boiler efficiencies should be assessed as this directly determines the value of the heat produced by the CHP unit.
- Discussions should be initiated with the gas and electricity suppliers. There is also a statutory obligation to inform both the gas supplier and the REC when installing CHP.
- Site defects should be recognised and preferably corrected before CHP is installed.

5. SELECTION OF UNIT SIZES AND TYPES

5.1 Manufacturers' Alternatives

The site investigation will have indicated the general size range of CHP units which can be supported by the heat demands of the building and/or its services. A review of the relevant manufacturers' alternatives should now be undertaken and a matrix of salient information prepared so that in due course an overlay can be made of outputs against the site requirements, and hence the costs and savings benefits established. These aspects are discussed in this section and a fully worked example is included in Appendix 3 together with calculation methods for analysing savings.

The comparisons should include an evaluation of the hardware itself as applied to the site characteristics established in the investigation. Contractual terms as well as maintenance and finance packages also need to be assessed and these aspects are addressed in Part D.

5.2 Generator Type

The different types of generator available have been discussed previously in Part A Section 2.2. In many instances the type eventually selected will be fundamentally determined by:

- actual usage requirements;
- the size of plant required;
- the site limitations;
- the need for standby power;
- budget considerations.

Most early small-scale CHP systems below 100 kW_e were generally based on asynchronous generators. Manufacturers now generally use synchronous generators reflecting the increased use of microprocessor control CHP and thus the marginal increase cost for synchronisation.

5.2.1 *Asynchronous Mains Excited*

The asynchronous generator, as previously stated, is one of the simplest of all possible rotating machines. Since the generator can also be used as a motor, some manufacturers choose to use it to start the engine. This does away with the need for batteries and the associated chargers, controls and auxiliary starting motors. In consequence there is less to go wrong and so it provides very reliable starting, although it does increase the current in the motor/alternator windings during start-up.

If CHP is being considered strictly from an energy cost reduction point of view and there is no requirement for standby power, the asynchronous generator with its simple installation requirements could be a good choice. Such machines are also marginally more efficient electrically than their synchronous counterparts at typically 93% as opposed to 90%.

5.2.2 *Self Excited Synchronous*

Where an emergency supply is required on site, a major advantage of the synchronous unit is that it can double as a fully controllable standby generator. This can dramatically alter the system economics as the cost of providing the standby power facility can be offset against the cost of the CHP system.

The units are always battery started, giving freedom from mains starting surges and thereby imposing less demands on the distribution network. System parameters can be ascertained and

checked prior to connection to the grid, thereby enhancing system security. The power output can also be modulated over a wide range.

A unit chosen for standby generation may be larger in terms of electricity output, and hence heat output, than one chosen for CHP use, and accordingly a deliberate reduction of output power may be necessary for part of the year.

5.3 Multiple v Single Units

Single CHP units are the preferred option, though either cramped conditions or restricted access may dictate the use of two or more small units in some situations.

The advantages of a single large unit are:

- maintenance costs per unit of electricity generated should be lower than for multiple small units;
- installation costs per kW_e output are likely to be lower;
- the electrical generation efficiencies of the larger units when operating at full power are slightly higher than those of the smaller units;
- in emergency standby use, single units can more readily achieve good supply regulation and control stability and thus ensure continuity of supply quality during mains failure.

The main advantage of multiple small units relates to the provision of standby power. It may be easier to guarantee emergency supply cover and also electricity maximum demand cost savings with multi-units; one of the several small units out of action for maintenance is generally less serious than one large unit out of service.

5.4 Electrical v Heat Output

Different sizes of CHP units will give slightly different proportions of electricity generated to heat recovered, according to the actual characteristics of the equipment selected.

Electricity, other than 'off-peak', is worth between three and ten times as much as heat, so generally, size for size, the greatest savings will accrue against the unit with the highest electrical generation efficiency, providing the overall efficiency of the unit is not adversely affected by poor heat recovery equipment.

5.5 Comparison of Specifications

When comparing machines it is essential to compare the manufacturers' specifications. For example, not all machines include an acoustic enclosure and electricity metering, yet both may well be required.

Technology does not stand still, so specifications change and manufacturers learn from both their own and their competitors' successes (and failures). The ongoing development which most manufacturers undertake means new features become available. In particular, considerable attention in recent years has been given to improving reliability and reducing both capital and maintenance costs by the application of low cost electronics, particularly for condition monitoring.

Most manufacturers are aware of the best features of their machines and will emphasise the strong points. This is not necessarily true with regard to limitations, and if competitive quotations are obtained something may be omitted in order to hold the price down.

A standard specification, providing it is drawn up carefully by the user, may help comparisons but it can also inhibit competitive tendering and technical innovation. All too frequently, specifications are limited to hardware and output expectations with little regard being given to maintenance or on-going product support. Specifications should require maintenance and after-sales service arrangements to be stated and costed: this aspect is further discussed in Section 7.1 and in Part D of this guide.

KEY POINTS

- The range of CHP units available should be reviewed together with the site characteristics and the heating and electrical consumption profiles in order to select most appropriate system.
- Where there is a need for standby power a synchronous generator will be required. Otherwise the type selected will generally depend on the size of plant and budget considerations. The greatest flexibility is likely to exist with a synchronous generator but possibly at an increased price for smaller units up to 100 kWe output.
- Greatest savings will generally be achieved with units with the highest electrical generation efficiency for a given heat recovery capability.
- A standard specification may help a comparison between units but it is important to ensure that maintenance and after-sales service arrangements are included.

6. ELECTRICITY, GAS AND COMPETING FUEL TARIFFS

6.1 Structure of the Electricity Supply Industry

The current structure for England and Wales came into effect on 1 April 1990, in accordance with the Electricity Act 1989 which governs the activities of the industry. The regulatory body is the Office of Electricity Regulation (OFFER), headed by the Director General of Electricity Supply (DGES). The basic structure comprises generation, transmission and distribution.

Generation comprises three main companies created by re-grouping the previously state-owned power stations, and independent generation companies. The main generators are Nuclear Electric (which remains in public ownership), National Power and PowerGen. Independent generators are new companies set up as commercial ventures in the normal way.

Transmission is via the national grid system which receives the outputs from the generators and delivers electricity to the twelve distribution regions of England and Wales. The system is operated by The National Grid Company (NGC), which is also responsible for the Scotland/England and France/England links, and the two pumped storage power stations. NGC co-ordinates the inflow and outflow of electricity so as to meet demand, ensure lowest cost to consumers and maintain transmission system technical integrity.

Distribution is effected by twelve companies created from, and operating over the same areas as, the previous regional electricity boards; originally termed public electricity supply companies (PES) they are now usually referred to as regional electricity companies (RECs). Each is responsible for the reception of electricity from the grid, and distribution and supply to individual consumers in its area. The twelve RECs jointly own NGC. A REC may have its own or part-owned independent generation company or companies, but may not produce more than about 15% of its requirements by this means.

In Scotland, the three generating companies - Scottish Nuclear Ltd, Scottish Power plc and Scottish Hydro-Electric plc - are each responsible for generation, transmission and distribution.

Up until March 1994 the RECs have a franchise market to supply all consumers within their area with maximum demands below 1 MW. In April 1994 the franchise limit will be reduced to 100 kW, and eventually abolished altogether in April 1998. These changes are likely to have a significant impact on the small scale CHP industry. It is too early to predict exactly what the impact will be, though it should provide opportunities for exporting electricity from CHP. In particular, from 1998, operators of group CHP installations will be able to sell electricity directly to tenants (in addition to heat which is currently sold).

Most small scale CHP operators will be below the 1 MW franchise limit and until April 1994 will only be able to purchase electricity from the local REC at published tariffs.

The choice of tariffs available to users reflects the complexity of their metering and the size and type of load. A domestic user might pay on a tariff with a single kWh rate, or perhaps on a 'two-rate' day/night tariff, such as 'Economy 7'. A commercial user on the other hand may have the choice of a 'Maximum Demand' (MD) tariff or a 'Multi-rate'/Seasonal Time of Day' (STOD) unit based tariff. STOD tariffs are increasingly favoured by the RECs as they more accurately reflect actual costs.

6.1.1 *Maximum Demand Tariff*

On this tariff electricity is purchased at a flat rate per unit, currently about 5p/kWh or on a two-rate day/night basis. On top of this there are charges for 'maximum demand', which penalises peak winter electricity use. There are also extra charges for 'availability', i.e. the commitment by the area board to provide a sufficiently large supply. There may also be charges for reactive current supplied.

This type of tariff makes calculation of the benefits (excluding savings from MD reduction), of a base-load CHP unit fairly simple since the CHP unit simply produces electricity at a flat rate, but at a cost less than that charged by the board.

6.1.2 Unit Based Tariff (Seasonal Time of Day)

Generally, if available, a STOD unit based tariff offers the CHP user the best option as maximum demand charges are embodied in higher winter unit prices so that temporary short-term purchase of electricity, for example when a CHP unit cuts out on temperature, does not result in the imposition of maximum demand charges for a whole month, or even longer.

Typical daytime rates are around 5p/kWh, though this rises to 35p/kWh or more during winter weekday afternoon periods (1600-1900h). Fig 6 gives an example of a STOD tariff.

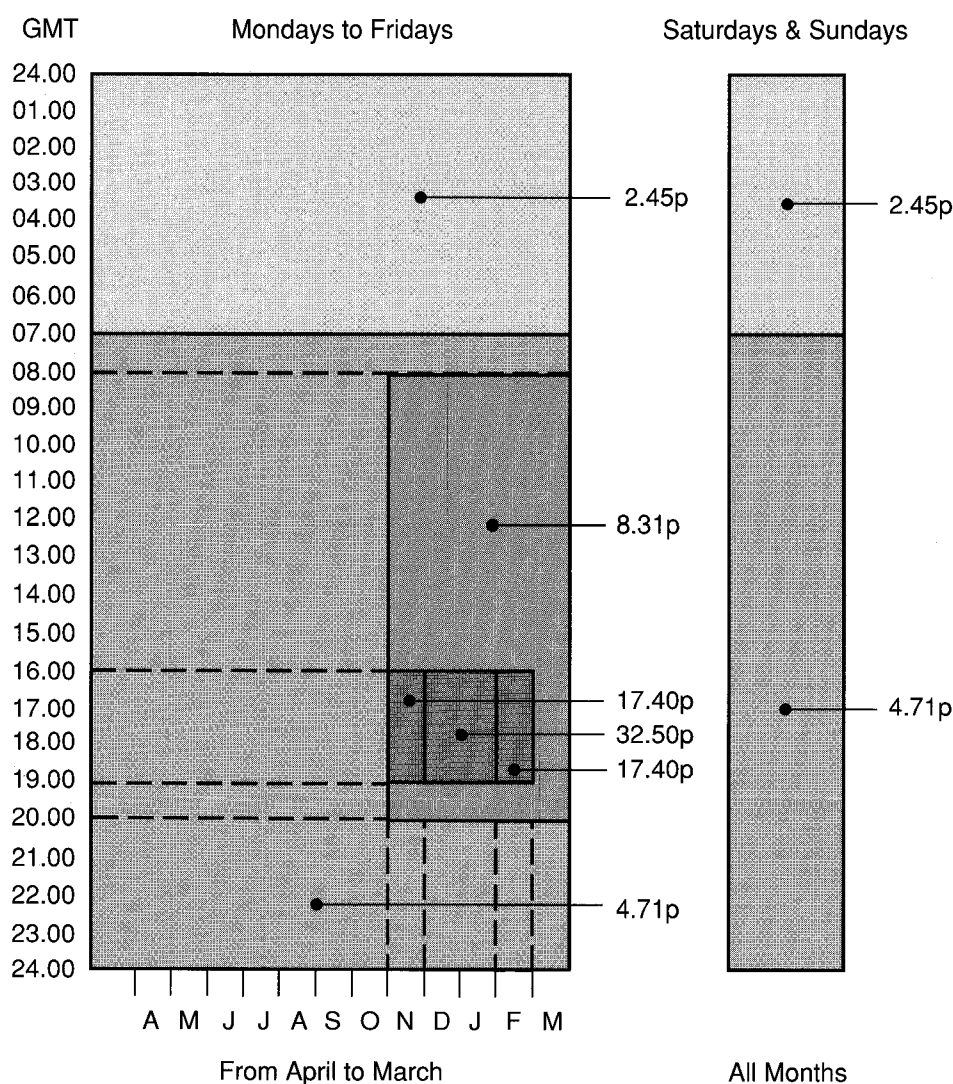


Fig 6: Seasonal time of day tariff for low voltage users, London Electricity plc (April 1992)

6.2 Gas Tariffs

There are three basic agreements under which gas can be purchased:

- Tariff: up to 25,000 therms/year
- Firm contract: over 25,000 therms/year
- Interruptible: over 200,000 therms/year.

Most small scale CHP operators will use between 25,000 th/year and 200,000 th/year and will therefore purchase gas on a contract. This will be on a scheduled price basis or through negotiation dependent on supplier. In general, the price will decrease as the gas consumption increases. It is important to recognise this when evaluating savings, since installation of CHP will increase gas consumption. British Gas publish price schedules - an example is shown below. Most independent gas suppliers* will negotiate individual contracts, based on patterns of consumption and total volume.

If the total gas consumption for the site exceeds 200,000 th/year interruptible gas can be considered, though an alternative source of fuel (typically fuel oil) must be available to ensure continuous operation of plant. Most small scale CHP plant can only operate on gas, so if interruptible gas is being considered, the savings calculation must take account of the period when the CHP plant cannot operate due to interruption of the gas supply. This could significantly affect the economics of the CHP system.

Block Tariff Prices (1/10/92)					
TIER	Therms	Price p/therm	MWh/year	Price p/kWh	Standing Charge
1	0 - 5,000	43.28	0 - 146	1.477) 10.1 p/day
2	5,000 - 10,000	41.28	146 - 293	1.409	
3	10,000 - 15,000	40.29	293 - 439	1.375	
4	15,000 - 25,000	39.29	439 - 739	1.341	
Scheduled Prices - Firm Gas (1/12/92) For single premises					Monthly Charge £
	25,000 - 50,000	37.74	733 - 1465	1.288	57
	50,000 - 100,000	37.50	1465 - 2931	1.280	67
	100,000 - 150,000	34.75	2931 - 4396	1.186	296
	150,000 - 250,000	33.75	4396 - 7327	1.152	421
	250,000 - 500,000	32.73	7317 - 14,654	1.117	629
Seasonal Pricing Factor for scheduled gas					
		Factor			
	December, January, February, March	1			
	April, May, October, November	0.95			
	June, July, August, September	0.85			

Fig 7 An example of gas prices (British Gas)

6.3 Competing Fuels

There are a number of alternative fuels available to the CHP user and which warrant consideration. The most commonly encountered are:

- gas oil (or diesel fuel, Class A);
- liquefied petroleum gas (LPG);
- biogas (methane gas collected from decaying biological waste).

* Details of independent gas suppliers can be obtained from the
Office of Gas Supply (OFGAS) - see address in Appendix 2

If other high calorific value gas, with a suitable octane number, is available, its use for CHP should be considered but the characteristics of the gas must be known and understood before its use.

6.3.1 *Gas Oil*

Gas oil enables higher electrical generation efficiencies to be achieved via the diesel cycle, but results in higher maintenance costs, through increased emissions and sooting. However, there are a vast number of experienced people capable of maintaining such plant and the units are of standard manufacture, as gas oil is the fuel generally used in standby generators.

The user has control over fuel stocks and can buy from many sources to provide the most competitive price. The user will also have to provide storage and manage his stock levels.

6.3.2 *LPG (Liquefied Petroleum Gas)*

LPG is a clean fuel readily consumed in CHP plant and most commonly encountered as a fork lift truck fuel on industrial sites. Nonetheless it is unlikely to be considered for CHP if piped natural gas is available because, unless purchased in large quantities, the cost is generally higher than for natural gas. Like gas oil, LPG prices rise and fall in accordance with world demand and availability.

Reasonable levels of stock can be held on site under the user's control but storage can be expensive and difficult. However, if the gas is already on site for other purposes it warrants consideration and could secure full 'interruptible' status for CHP under the right conditions.

6.3.3 *Biogas*

Often considered a 'free' fuel, though this is not quite so, for even when available, special consideration must be given to its use. In consequence, both capital and maintenance costs tend to be higher. If available, it should not be discounted and in sewage treatment plants is very appropriate.

The use of biogas as a fuel must be drawn to the engine manufacturer's attention due to the presence of Hydrogen Sulphide (H_2S) and the excess water in the gas. Generally the engine manufacturer will ask for an assurance that the level of Hydrogen Sulphide will not exceed an agreed maximum, typically 500 ppm.

KEY POINTS

- A knowledge of the structure of electricity tariffs is necessary in order to calculate the savings and operate the unit to the best advantage during different time periods.
- A unit based, or STOD, tariff generally offers the best option over a Maximum Demand (MD) tariff since temporary short-term purchase of electricity does not result in the imposition of MD charges for a whole month.
- Firm contract gas supplies are subject to special agreements with British Gas or negotiation with independent gas supplies. The use of the lower priced interruptible gas may not be economic due to loss of operating hours during interruption.
- Gas oil, LPG and biogas are the most commonly encountered alternative fuels and their economic use depends on a comparison with the cost and availability of a natural gas supply.
- Where CHP is substituting for heat normally obtained from dual fuel boiler plant the CHP system will only prove economic when the fuel used in each installation is of similar cost.

7. SAVINGS AND CAPITAL COSTS

To evaluate accurately the true savings potential from CHP, and to ensure that when installed it is used to generate electricity only when cost effective, requires detailed calculations.

7.1 **Marginal Generation Cost**

As part of a heating system, a CHP unit should be running as an alternative to an efficient boiler. Therefore a choice has to be made whether to buy in electricity from outside and use the boiler for heating, or to generate electricity using the CHP unit and recover the waste heat. To make the correct decision requires calculation of the marginal cost (or costs) at which electricity can be generated. This is determined by several factors.

- electricity savings, i.e. the cost of electricity displaced by CHP;
- the cost of gas (or fuel oil);
- the heat production efficiency of the boilers;
- the heat production efficiency of the CHP unit;
- the electricity generation efficiency of the CHP unit;
- maintenance costs.

CHP maintenance costs are higher than those of a boiler due to the considerably more complex nature of the CHP unit and it is essential that these are accurately determined and included in the cost of generation.

7.1.1 *Additional Fuel Cost*

From utility bills, site data and manufacturers' data sheets determine, for each size of CHP unit under consideration:

Cg	-	cost of fuel (p/therm)
Eo	-	electrical output of CHP unit (kW)
Ho	-	heat output of CHP unit (kW)
Fi	-	fuel input (kW)
Ub	-	boiler efficiency (%)
Fx	-	cost of extra fuel (p/kWh electricity)
Fx	=	$\frac{1}{Eo} \times \frac{(Fi - \frac{100Ho}{Ub})}{29.31} \times \frac{Cg}{29.31}$

For example for a 90 kWe unit running on natural gas at 35p/therm, the cost of extra fuel (Fx) works out at 1.34p/kWh based on 180 kW output (Ho), a gas fuel input of 338 kW (Fi) and a boiler efficiency (Ub) of 76%.

7.1.2 *Relative Fuel Costs*

In assessing the benefits of installing CHP, the significance of the relative fuel prices involved must not be overlooked for it can have a major impact on the savings benefits.

If CHP heat is substituting for boiler heat sourced by the same fuel at the same price (or different fuels which cost the same or a very similar price when expressed in the same units), then the fuel price has only a marginal effect on CHP profitability, (by virtue of the cost of the additional fuel used due to the lower thermal efficiency of the CHP plant when compared to the boiler).

On a site with an interruptible gas supply to the main boilers it may not be economic to operate the CHP unit on this supply since loss of operation could significantly reduce annual running hours and hence savings. Use of firm gas for the CHP supply would not be economic if interruptible gas is used for the main boiler plant.

7.1.3 Maintenance Cost

Because maintenance of CHP units is more expensive than for boilers it must be taken into account when calculating savings. Current experience suggests that overall maintenance costs will lie in the range 0.5 to 2.0p/kWh of electricity generated. The manufacturers should be consulted for this figure but, as a guide, 0.7p/kWh should be used as fairly typical. Comprehensive maintenance contracts are now available from most equipment suppliers. If the CHP plant is installed under an alternative financing arrangement, this will usually include maintenance.

It is essential that proper comparisons are made and, to facilitate this, life cycle maintenance costs should be carefully established with the CHP manufacturer. The life cycle costs should include routine service and lubrication costs as well as top-end and complete overhaul costs, all on an annualised basis.

Thus, comparison of costs over a period of at least 25,000 h operation should be undertaken. The maintenance costs will also depend on the level of service required. This can range from the use of in-house staff to undertake basic servicing tasks, representing the lowest cost, whilst a fully-inclusive maintenance service incorporating emergency call-out service will be the most expensive option.

7.1.4 Typical Marginal Cost

For the above example, assuming 0.7p/kWh for maintenance, a total marginal cost of 2.0p/kWh of electricity generated is produced (1.3p/kWh for extra fuel and 0.7p/kWh for maintenance).

Thus it is apparent that, as electricity at the present time can generally be purchased at night for around 2-2.5p/kWh, it is not economic to generate during such periods, except in an emergency. Most small scale installations are therefore shut down during the cheap electricity rate period.

7.2 Determination of Savings

The marginal generated electricity cost can be used to calculate projected savings using either a simple flat rate approach or by reference to load profiles, both electrical and thermal, and electricity tariffs.

7.2.1 Flat Rate Calculation

The simpler approach is quite satisfactory if the CHP heat and electrical outputs both fall well within the site energy requirements as determined from the utility bills and a multi-rate tariff is not in use. On this basis the annual savings will be:

$$\text{Savings (£)} = \text{Hours run per year} \times (\text{Electricity purchase price} - \text{Marginal generating price}) \\ \times \text{Electrical output of CHP unit in kWe}$$

In practice, typically there could be up to a further 10% saving resulting from a reduction in maximum demand charges in winter. This does of course depend on the unit having been sized correctly and operating reliably at its full rating. Generally MD savings should not be included in the main financial assessment.

If the CHP unit is more closely matched to the site's heat and/or electricity requirements, or a multi-rate tariff is in force, then the savings will need to be calculated by reference to the profiles obtained initially from the site investigation.

7.2.2 Full Cost Benefit Analysis

This process can be done manually in graphical form or preferably using a spreadsheet set up on a personal computer (PC).

The following procedure should be used, based on the data collected from site:

- taking into account boiler efficiencies, set out heat profiles, obtained preferably hour by hour from meter readings or event recorder, against calendar time;
- superimpose heat output of CHP unit under consideration and determine hours run and hence, electricity generated in each tariff calendar/time block;
- compare with site electricity demand profile (if relevant) to establish if export or used in-house;
- find totals of each category of kWh, multiply by monetary value of kWh minus marginal cost of generation;
- determine total annual savings by adding up all blocks;
- repeat whole exercise for each CHP unit under consideration;
- add savings from Maximum Demand reduction if appropriate;
- deduct from savings annual charges for additional facilities provided i.e. availability and metering charges if any;
- determine payback from installed capital costs, based initially on £600/kWe, assuming no undue complications;
- where appropriate, fully assess the cost implications of the range of finance and maintenance options provided by CHP suppliers;
- obtain specific quotes for proposed system(s);
- establish actual/discounted cash flows/NPV as customary before accepting the cost-effectiveness and making a decision to proceed. When CHP plant is being considered as an alternative to boiler or standby generator purchase or replacement it is appropriate to reflect in the calculation the capital cost of these alternatives.

Alternatively use proprietary CHP evaluation software which is now available or have the CHP system manufacturers run the data through their computer programs. It is important to establish any assumptions used in the calculations to ensure that they relate realistically to the site under consideration.

KEY POINTS

- Annual operating hours, maintenance costs and fuel and electricity prices need to be known in order to calculate savings.
- Savings depend on the calculation of the marginal cost(s) at which electricity can be generated; currently this is typically about 2.0p/kWh of electricity generated.
- Maintenance costs should be carefully assessed and life-cycle maintenance costs carefully established with the CHP manufacturer. Current maintenance costs are in the range 0.5-2.0p/kWh although actual figures will depend on the detailed maintenance requirements, unit size, and in-house resources.
- Most CHP system manufacturers will provide a computer assessment of projected savings, but it is important to establish the basis of the calculations to ensure realistic estimates.
- Equipment supplier maintenance contracts generally provide the most convenient method of ensuring CHP plant reliability.
- Finance packages for CHP implementation are available from many suppliers.

PART C: INSTALLATION OF CHP SYSTEMS

NOTE:

Readers not requiring detailed technical information on CHP installation should skip sections 8-11 and move on to Part D (page 54)

8. INSTALLATION AND CONNECTION WITH EXISTING BOILER PLANT

The selected location for the CHP system must take account of the following:

- delivery, access and positioning;
- noise emission;
- exhaust emissions;
- ventilation requirements, typically 0.03 m³/s for every kW_e of installed capacity;
- access to services; electrical, heating and fuel supplies;
- maintenance requirements.

Generally the CHP units will be skid mounted with the small units able to be man-handled through a standard doorway. The larger units may need positioning by crane or alterations to the building in order to accommodate them. Some manufacturers offer weatherproofed and fully silenced units intended to stand outside. However, before siting a unit either outdoors or in the cold, the supplier's views should be sought. Unless engine pre-heating and oil circulation is provided, cold starts in the depths of winter may cause problems and at the least, will result in increased engine wear.

If the CHP is being installed in an existing boiler house it is more likely that ventilation requirements will be met. Mechanical services plants' rooms on the other hand, are often unventilated and thus ventilation may be required.

A level surface should be provided which is neither subject to flooding nor liable to suffer from effects of vibration. If the latter is thought likely, consideration should be given to the use of anti-vibration mountings. Provision should be made for maintenance and for example for heat exchanger dismantling and cleaning as this will be required at some point in time.

8.1 Heating System Connection

There are essentially two ways of connecting a CHP unit into a heating system:

- 'in series' as a bypass in a suitable return water feed to the boilers, commonly, though not necessarily, the main return;
- 'in parallel' with the boilers.

The two options are illustrated schematically in Fig 8.

Series connection is the most common but which of the two methods is selected and precisely how the CHP is connected will depend on the number and size of the CHP unit(s) and on the site appraisal, particularly with respect to water flow rates and return temperatures. A dedicated CHP system could supply heat to only the DHW (or process) or to the heating system, either at local level or in conjunction with the central boiler plant.

8.1.1 Series Connection

The bypass connection is frequently selected as the most suitable for introducing CHP into an existing installation, since it creates the minimum interference with existing flow and control

arrangements. The water flow and return connections to the CHP unit are made via tapplings, generally off the main return pipe from the radiators and/or hot water calorifier. The CHP circuit has its own pump and the flow rate through it is likely to be far smaller than the flow through the main heating circuit. Extra units can be connected in a similar way.

In winter the boilers will operate to provide the peak heat loads. In summer it is probable that only one boiler will be operational and the flow path through it must be left open to allow the CHP unit to function correctly. This may lead to increased boiler standing losses. If motorised isolating valves are fitted to the boiler(s) a bypass will be required which will allow at least the minimum CHP water flow to pass.

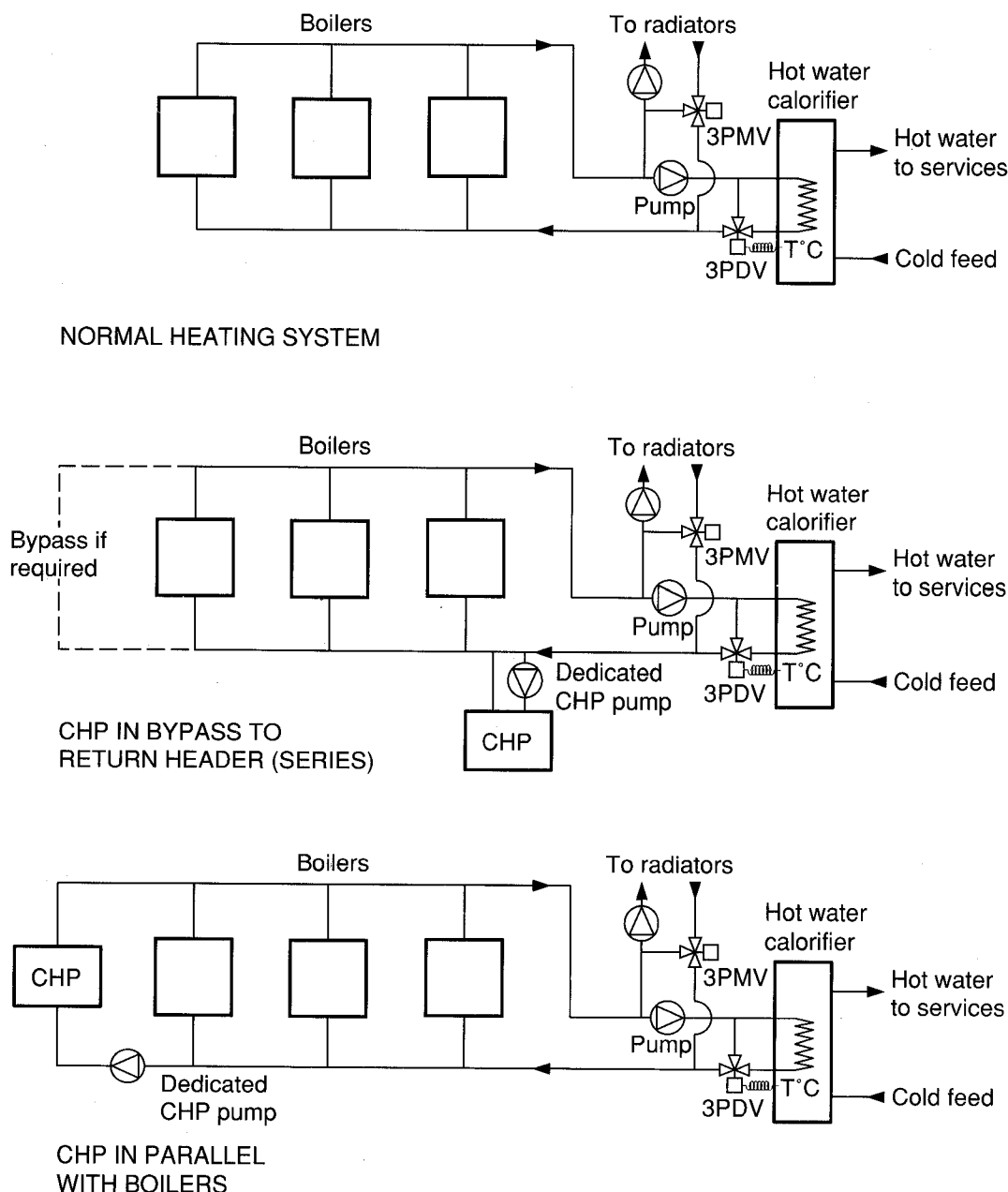


Fig 8 Examples of CHP/heating system connections

8.1.2 Parallel Connection

When setting up a totally new installation, especially where the CHP unit is likely to supply a significant proportion of the total heat load, it is better to install the unit in parallel with the

boilers. This is particularly important if the boilers are to be controlled in such a way that the flow through the boilers drops significantly under certain conditions. However, it is important to ensure that the volumes of water flow through the CHP unit and the boilers are correctly balanced.

Due to high hydraulic resistance of CHP units, as compared to boilers, an additional pump, specific to the CHP unit(s), will generally be required.

Care is needed to ensure that the positions of the CHP tapings are chosen not for convenience alone, but also for suitability, i.e. to ensure the correct volume of water at suitable temperatures.

8.2 Connection to CHP Unit

Heat is extracted from the engine in a number of separate ways:

- from the engine jacket and cylinder head cooling water;
- from a high temperature heat exchanger in the exhaust;
- optionally; from a low temperature condensing heat exchanger in the exhaust and sometimes from the unit housing and/or alternator.

Refer to Section 2.3 in Part A for detailed information on the heat exchanger characteristics and operation.

8.2.1 *Cylinder Head and Engine Jacket*

Heat is normally extracted from the engine jacket and cylinder head and, if fitted, from the oil cooler, all through a separate loop of water containing an ethylene glycol antifreeze mixture as a corrosion inhibitor. The corrosion inhibitors should be to BS3926, BS4959 and BS5117. Typically a 25 - 40% mixture is used.

8.2.2 *Exhaust Heat Exchanger*

The exhaust heat exchanger, being specifically designed for the purpose, unlike the engine block, can carry the primary water of the heating system, i.e. the water which circulates through the boiler. Although this water may contain limited corrosion inhibitors, it may be expensive to treat the large volume of heating system water to the level required for the engine block, the latter being considerably more demanding than the exhaust heat exchanger. In order to prevent excessive scaling, the exhaust heat exchanger must not carry untreated (raw) mains water. Many manufacturers use an intermediate plate heat exchanger interfacing between the heating system and the engine and exhaust heat exchangers.

8.2.3 *Condensing Heat Exchanger*

An exhaust condensing heat exchanger, where fitted, carries low temperature water, usually for such purposes as swimming pool heating or DHW preheat. In this case the water is heated directly, without any intermediate circuit of treated water. Because of the possible chlorine content of swimming pool water, the heat exchanger will normally be made of cast iron or stainless steel. If the heat exchanger is used for preheating cold mains water and/or DHW preheat, then it should be checked regularly for signs of scaling.

Since most of the water vapour in the exhaust gases condenses out inside this heat exchanger, care must be taken in the installation for the proper drainage of the condensate (see Section 11 below), particularly when first starting up when the system is at its coldest and condensation takes place to a greater extent than during normal running.

8.3 Pipework Requirements

8.3.1 Pipe Specification

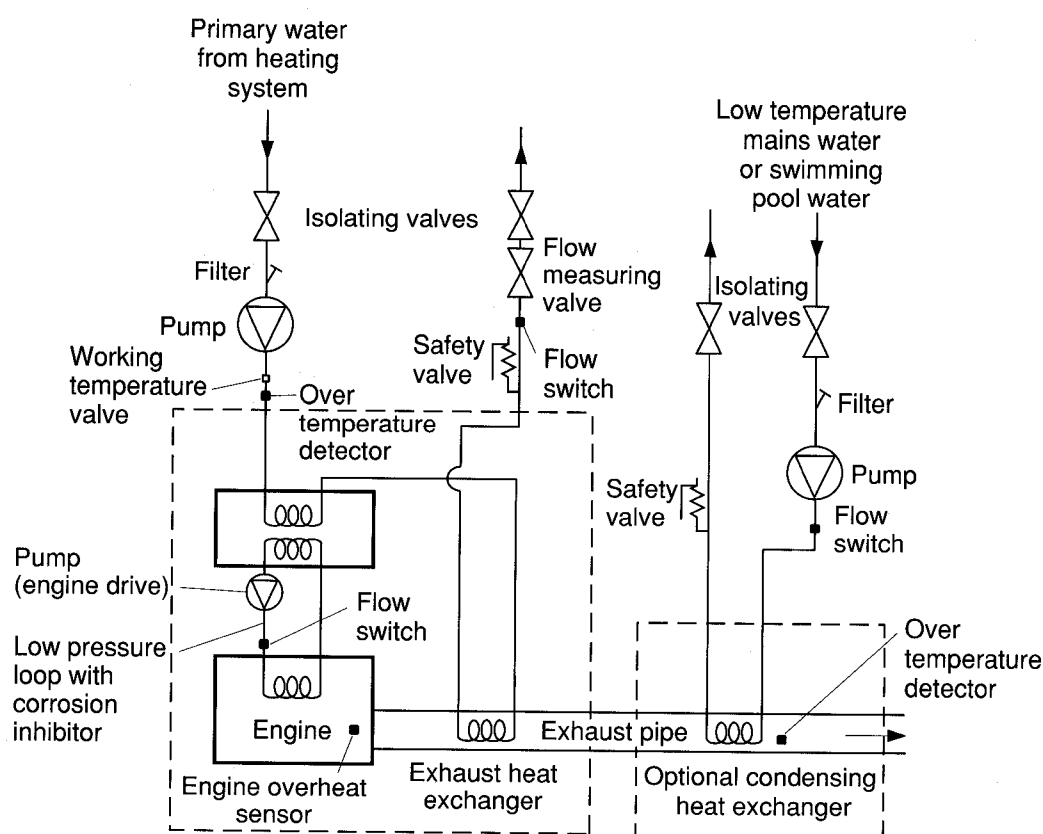
The pipework for connecting the CHP unit to the heating system should generally be installed in accordance with BS1965, BS21 and BS1387. Care should be taken when making the connections to ensure undue strain is not imposed on the heat exchanger connections and that the pipework in the vicinity of the engine is adequately supported to enable disconnection of the unit if necessary. Flexible couplings are best used for this and have the added advantage that they also minimise transmission of vibration. Swimming pool water is corrosive and suitable materials need to be used in contact with it. Commonly used materials for pipework are cast iron, stainless steel and ABS plastic. Gunmetal is suitable for valves and fittings while brass should not be used.

8.3.2 Isolating Valves

Isolating valves should be provided to allow disconnection and maintenance of the whole CHP unit and also parts such as pumps and filters, without draining down the whole heating system.

8.3.3 Filters and Drains

Consideration should be given to installing a mesh strainer and dirt pocket to intercept debris circulating in the heating system before it reaches the CHP unit. These strainers *must* be regularly checked and cleaned. Strainers are a precaution against debris but are not intended to filter out significant quantities. Where a condensing heat exchanger is used for heating swimming pool water, the water supply should first pass through the pool filtration system.



Note: Some units may also include oil cooling, generator cooling and/or cabinet cooling, heat recovery circuits.

Fig 9 Typical CHP piping configuration.

Fig 9 illustrates how a CHP unit could be configured for direct connection to the heating services and to a swimming pool. A single interfacing heat exchanger may also be used for connection to the heating services, dependent on the equipment supplier.

8.3.4 Test Points

At critical points in the flow and return pipework of each circuit, it is recommended that Binder* or equivalent test points are provided. By enabling direct access to the water itself, these allow accurate measurements of temperature and pressure and considerably speed up initial setting up and fault finding.

Permanent indication of temperature should be made by thermometers inserted into proper test pockets in the flow and return pipework. Strap-on dial thermometers should be treated with caution, especially when measuring small temperature differences.

8.3.5 Insulation

On completion and after satisfactory testing for water leaks, all pipework other than exhausts and plastic pipework should be insulated using glass fibre rigid sections, canvas covered and clipped in position. Alternatively, if a suitable standard exists for the site, the insulation should match it.

8.4 Pump Sizing

It is essential to ensure that all pumps supplying water to the CHP units are adequately sized to meet the CHP unit manufacturer's recommendations. If the pumps are under-sized then adequate flow rates through the CHP units are not achieved, thereby causing overheating and tripping of the engine.

In calculating the required pump head, allowance must be made for resistance due to:

- the CHP unit, including associated heat exchangers, with 15-20% fouling factor;
- connecting pipework and bends;
- isolating valves;
- water meters;
- strainers and/or filters;

8.5 Safety Switch and Sensor Installation

Overheating or failure of the cooling water supply to any of the heat exchangers can have catastrophic results. It can result in cracked engine cylinder heads, damaged heat exchangers or burst water hoses.

As a minimum precaution, an over-temperature detector should be inserted in the return water feed to the engine. It is also highly desirable that water flow switches be incorporated in all water feed pipework to the CHP unit to ensure that the engine shuts down in the event of a pipe blockage or failure of any of the heat exchangers. This should be in addition to electrical control interlocks with the various pumps.

The positioning of the flow switches should be so arranged that they can be tested periodically. When fitted correctly, the sensors will protrude into the pipe in an area of turbulent flow. This is often best achieved at a bend in the pipework by use of a swept 'tee' fitting rather than an elbow.

* Binder is the registered trademark of Binder Engineering of Banbury, Oxon.

KEY POINTS

- CHP plant should be located to ensure that access, noise emission and ventilation requirements are met.
- Connection of the heating system can be either in series or in parallel and will depend on the site conditions.
- In general, mains cold water should not be directly connected to the engine jacket and exhaust heat exchangers, in order to prevent excessive scaling.
- Condensate drainage should be installed in the exhaust heat exchanger(s).
- Pipework should be installed in accordance with the relevant British Standards. Special materials such as cast iron, stainless steel or ABS plastic are required for swimming pool water.
- All pumps supplying the CHP units should be properly sized in accordance with the CHP manufacturer's recommendations.
- Sensors should be fitted to prevent overheating on failure of the cooling water supply.

9. ELECTRICAL INSTALLATION

9.1 Regulations

It is a statutory requirement that the local Regional Electricity Company (REC) is consulted if there is any possibility of electrical generating plant being connected in parallel with their system. In practice, it is essential that the REC technical department is consulted at a very early stage.

In addition, the Secretary of State for Trade and Industry must be notified of all generating plant having a capacity greater than 200 kWe. It should also be noted that the Director General for Electricity has a duty under Section 47 of the Electricity Act 1989 to collect information on the generation, transmission and supply of electricity. The Office of Electricity Regulation (OFFER)* is establishing a database of CHP installations.

The electrical installation work must comply with the relevant statutory requirements. These are detailed in the following documents which also include Recommendations and Codes of Practice as guidance to achieving compliance with the legislation:

- 16th Edition of the IEE Wiring Regulations. This is the reference source for regulations covering Electrical Installations
- Electricity Association Engineering Recommendation G59/1; Recommendations for the Connection of Embedded Generation Plant to the Regional Electricity Company's Distribution System, 1991
- Electricity Association Engineering Technical Report ETR113; Notes of Guidance for the Protection of Private Generating Sets up to 5 MW for Operation in Parallel with Regional Electricity Companies Distribution Networks, 1989
- Electricity Association Engineering Recommendation G5/3 'Limits for Harmonics in the UK Electricity Supply System'
- Electricity Association Engineering Recommendation G12/2 'National Code of Practice on the Application of Protective Multiple Earthing to Low Voltage Networks'
- Guidance Note PM53 from the Health and Safety Executive 'Emergency Private Generation - Electrical Safety'
- Electricity Association Engineering Recommendation P28; Planning Limits for Voltage Fluctuation Caused by Individual Commercial and Domestic Equipment in the UK, 1989.

The use of a contractor who is registered with the National Inspection Council for Electrical Installation Contracting (NIC-EIC) should ensure compliance with above. The installation should also comply with the requirements of the Factories Act (Electricity).

Electricity Association Engineering Recommendation G59/1 is particularly relevant to CHP installations and details the main provisions for connection to the electrical mains. It should be referred to in conjunction with this document.

9.2 Switchgear Requirements for Connection to System

9.2.1 *Non-Standby Operation*

The CHP generator will normally be connected, via its control panel, to the consumer's side of the REC's metering equipment. The most common connection point is the main distribution

* See Appendix 2 for address.

board of the building, but on large systems connection at a sub-distribution board may be necessary. Where significant electricity is generated surplus to the site requirements, the installation of export metering should be arranged with the REC.

For safety and maintenance purposes there must be provision for electrical isolation of the CHP system at each end of the supply cable. Generally this requirement will be met at the CHP end of the cable by the isolator fitted in the control panel so that only the isolator at the point of connection to the building's electrical services has to be supplied extra. *Both isolators must be lockable only in the open circuit position and suitable padlocks for this purpose should be supplied and only one key to each should be permitted.*

9.2.2 Standby Operation

If the CHP unit is to supply emergency electrical power automatically in the event of a mains failure, then in addition to the aforementioned switchgear, the following will also be required:

- automatic isolator to disconnect the site electrical network from the grid (sometimes included in the CHP panel);
- a number of automatic isolators to disconnect non essential circuits from the generator and to ensure that the remaining connected load does not exceed the CHP unit's continuous electrical output or the life of the unit may be prejudiced;
- a contactor to connect the star point (neutral of the generator to earth (unless 'ad hoc' approval has been received from the REC));
- an automatic battery powered generator starting system.

All switchgear should be adequately rated for the requirements, especially when starting currents on asynchronous generators are involved. Where possible, consult the site electrical engineer for preferred manufacturers as many engineers hold strong views on such matters.

The automatic mains isolator will also require interlocking with the CHP unit's control circuit.

9.3 Cables and Sizing

9.3.1 Cable Types

Cables should normally be selected from one of the following types and comply with appropriate British Standards:

- non-armoured PVC insulated cables (BS6004, BS6321 Type B or BS6346) or armoured to BS6346;
- split-concentric copper conductor PVC-insulated cables (BS4553);
- rubber-insulated cables (BS6007);
- impregnated paper-insulated non-draining cables, lead-sheathed (BS6480);
- armoured cables with thermosetting insulation (BS5467).

Machine Size kWe	Current at Full Load Amps	Starting Current for Normal Running Amps
26	50	97
40	65	150
90	140	325
125	194	465

9.3.2 *Main Power Cable Sizing*

The cable connection to the generator should be sized to deal with the larger of the full output current, or the maximum fault current. In addition, for asynchronous units, it should be sized to deal with the starting current which will be appreciably larger. Typical starting currents for such units are as follows:

The cross-sectional area of the cable should be determined in accordance with Appendix 4 of the IEE wiring regulations. If connected to a sub-distribution board and it is intended, if possible, to utilise existing cables, then there must first be recognition of the different conditions to which the site network will be subjected with the addition of the CHP generator.

The neutral conductor may have a reduced cross-sectional area, appropriate to the expected value of neutral current, where relatively balanced loads are experienced or where serious imbalance is unlikely. Notwithstanding this, the cross-sectional area of the neutral conductor must be adequate to afford compliance with IEE Regulation 524-02 for the maximum current likely to flow in it. Reduced neutrals are not permitted where the load generates significant harmonics e.g. from the control gear of discharge lamps, or there may be a significant inequality of loading between the phases. Generally, due to the uncertain composition of existing and future loads, it is convenient for the neutral conductor to have the same cross-sectional area as the phase conductors.

At the point of connection of the main power cable to the generator, consideration should be given to the need to allow for cable flexing, especially if the generator itself is on flexible mounts and the cable is thick. To achieve this flexibility may entail the use of a special short flexible cable connected via a floor-mounted terminal box. For smaller cables a generous loop of the cable should be allowed before connection to the generator.

All cables must be adequately supported in accordance with BS162 and BS159.

9.3.3 *Example*

Consider the network shown in Fig 10. The distribution boards D1, D2 and D3 are all existing, as are cables C1 and C2. With no on-site generation, C1 will have been sized for the combined loads of D2 and D3 (300 amps).

At first sight, if the generator is synchronous and has its own battery starting facility, then cable C1 is adequate: At no time will its 300 amp rating be exceeded even if the mains is interrupted and the generator carried the whole of the load D1 (the essential services).

In practice, due to the resistance of the cable, the voltage at D1 will fluctuate according to the source of the power:

- when supplied by the mains it will be 'high' as D1 is adjacent to the incoming mains;
- when supplied by the generator it will be 'low' due to the voltage drop along C1.

Whilst this may not be significant for most plant, if there is voltage sensitive equipment installed as part of the essential services, it is well to establish the predicted voltage drop by calculation and verify that this is acceptable.

In addition, if the voltage sensing relays providing G59/1 protection are located at the generator end of the cable, as is usually the case, unless the cable is generously sized there may be difficulty in establishing a set point which meets all operational conditions without giving rise to nuisance shut-downs.

For an asynchronous generator with mains starting, the cable will have to carry not only its normal 300 amp load but also, for a short period, the full starting current of the generator which, in the instance shown, is 465 amps. This will clearly result in unacceptable voltage dips to D2 and D3 users. Consequently, almost certainly a larger cable will be required, though this can take the form of a second cable (of equal size, type and length) as it may be easier to run an additional cable rather than a new larger one. Alternatively, for example, C3 can be taken off D2 and a separate smaller cable exclusive to D3, run back to the incoming mains supply point.

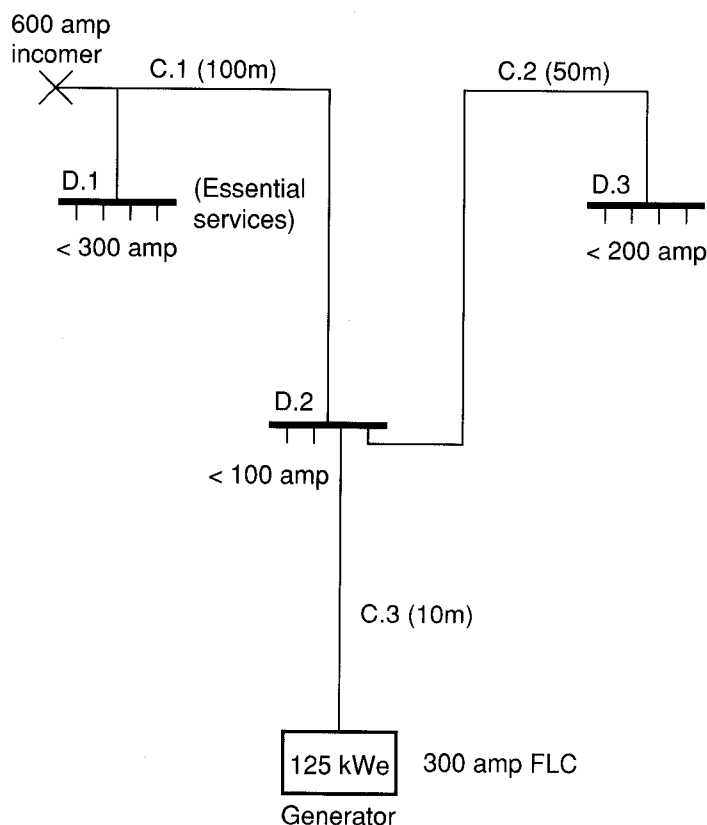


Fig 10 Electrical distribution network

9.3.4 Control Cables

PVC/SWA/PVC or mineral insulated PVC sheathed cable of appropriate cross-section, but less than 1.5 sq.mm, should be used for all 240 Va.c. wiring. Mineral insulated cable should not be used for circulating pumps, where some flexibility is required.

Low voltage cables to sensors and control switches should follow the manufacturer's specifications and in general should be in their own protective trunking and kept well clear of hot engine parts. If this is not practical, heat resistant and/or mains voltage rated cables should be used.

Electric cables should not be run in the same closed trunking as gas or hot water pipes.

9.4 Earthing

Earthing will generally be the aspect of the electrical installation requiring most attention. This is because G59/1 requirements mean that CHP systems require an earthing system which in general does not depend on the REC system. Protective Multiple Earthing (PME) is particularly appropriate for CHP systems. In this section the technical aspects of earthing are discussed together with specific earthing requirements.

Before discussing the requirements for CHP earthing, it is necessary to distinguish between 'earth' and 'neutral'.

- An 'earth' is a safety connection which should be at the same potential (voltage) as all exposed metallic parts of the building and machinery. It should never carry any appreciable current except in order to blow fuses or trip safety relays.
- A 'neutral' is a connection back to 'earth' at the REC's substation where it connects with the centre (star point) of the three-phase supply transformer winding. In three phase systems the neutral wire, in practice, carries current due to imbalance between the loading of three phases of the supply while in single phase systems neutral conductors carry the same current as the main conductor.

9.4.1 *Earthing Systems*

There are three commonly encountered earthing systems, each having slightly different 'earth' and 'neutral' arrangements. (See Fig 11):

- TT System: this is the standard arrangement for most installations fed from an overhead supply. The earth and neutral conductors are quite separate within the installation. No earthing terminal is provided by the Board and the consumer must supply his own.
- TN-S System: the majority of installations fed from an underground cable supply are of this type. The cable contains three phases and a neutral plus an earth conductor in the form of the metallic cable armour. The consumer's earthing terminal is connected to this which provides a connection back to the star point and earth electrode of the substation transformer.
- TN-C-S System: this is protective multiple earthing (PME). The supply from the substation consists of three phases plus a combined earth and neutral conductor. This should be connected to the main earthing terminal of the installation and locally earthed from there. Within the installation, the earth and neutral conductors should be treated as separate, allowing the use of earth leakage circuit breakers without interference from neutral line currents.

In general the installation must be designed to provide protection both by the use of earthed equipotential bonding (i.e. earth straps) and by automatic disconnection of the supply (IEE Wiring Regulations 413-02).

Cables are sized such that there is negligible potential difference between earth and neutral. In practice, if the distance to the substation is great, then there may be a few volts difference between a separate neutral and a local earth terminal at the installation.

9.4.2 *Earthing Requirements*

An existing building will have an earthing system already installed, but this may not be adequate for CHP. This is especially so if the CHP unit is to be used as an emergency generator. When operating in stand-alone mode the REC cannot be relied upon to provide the safety earth and in any case the site neutral conductor will no longer be connected to the supply. Thus, the building's earthing arrangements should be thoroughly checked utilising the services of an appropriately qualified engineer or in conjunction with the REC if necessary, in order to establish suitability for CHP.

The essential implications when installing CHP are that under G59/1 the CHP unit must have an earthing system which does not depend on the REC. Only if written permission is obtained can the substation earth be utilised. This permission is normally only given if the substation is on the consumer's premises and adjacent to the CHP unit.

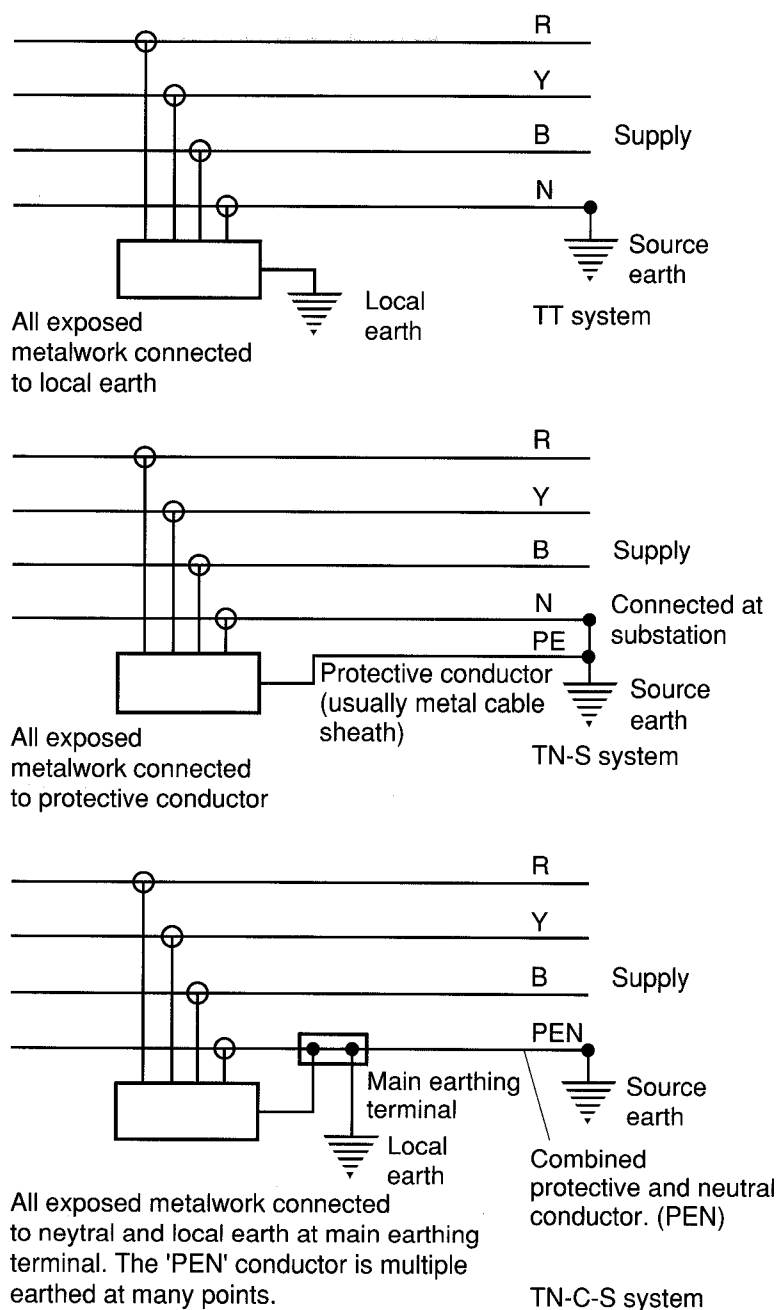


Fig 11 Earthing system

Protective Multiple Earthing is a type of distribution system with specific earthing arrangements and sizing of protective bonding conductors which is particularly pertinent if standby generation is intended. The system centres around the main earthing terminal of the installation to which are connected:

- the REC earth or earth/neutral as indicated above;
- an 'earth conductor' to an earth electrode buried in the ground;
- various 'protective conductors' which earth separate pieces of equipment.

All exposed metalwork in the installation should be earthed.

The installation itself must have a satisfactory earth of its own, separate from that of the REC, which should have a resistance to 'true' earth of not more than 20 ohms.

The following types of earth electrode are acceptable:

- buried earth plates, rods, pipes, tapes or wires;
- metallic reinforcement of concrete;
- metallic pipe systems, but not those of public gas or water supplies;
- lead sheaths and other metallic coverings of cables which are not liable to corrosion;
- other suitable underground metallic structures.

This earth electrode must be connected by an 'earthing conductor' to the installation's main earthing terminal. This conductor should not be aluminium because of corrosion problems. Copper or steel are acceptable. The size required will depend on the size of the main power supply cables, but is likely to be of at least 25 sq.mm of copper or 50 sq.mm of steel.

The connection of the earthing conductor to the earthing electrode should be visible for inspection and have an indelible label fixed to it marked '**SAFETY ELECTRICAL EARTH – DO NOT REMOVE**' in letters at least 5 mm high.

The main earthing terminal will also link together the protective conductors which earth individual pieces of equipment. Bonding should also be made to the gas and water supplies where they enter the building.

The size of all these conductors should be calculated in accordance with the Electricity Council Engineering Recommendation G12/2 and Regulation 543-01 of the IEE Wiring Regulations.

Earthing connections should not be easily removable and should carry tags, marked as stated previously.

All machine covers which are removable to allow access to components at potentials of 250 volts or more should be marked '**DANGER VOLTS**' in accordance with BS2771.

A warning notice should also be prominently displayed as follows:

'DANGER – THIS MACHINE IS AUTOMATICALLY CONTROLLED – DO NOT WORK ON IT UNTIL STARTING EQUIPMENT IS ISOLATED OR DISCONNECTED'.

9.4.3 Star Point Connection

For normal operation in parallel with the grid, the star point of a synchronous generator will not be connected directly to earth, but to the system neutral which itself is connected to earth at the substation transformer star point. Thus the star point of the generator is connected to the substation earth via the transformer neutral and not via the generator unit earth.

Out-of-balance phase currents will then circulate through the star point of the substation transformer.

When a generator is used for standby operation and the connection to the grid is broken, then it becomes necessary to earth the star point of the generator for safety reasons. If this was not done, the system neutral within the installation would fluctuate wildly around earth potential. Accordingly this is a requirement under the Health and Safety Executive Note PM53.

Where multiple synchronous generators are used in parallel for emergency standby generation, only the star point of the largest machine should be earthed. The rest should be left 'floating'.

The G59/1 recommendations do not allow a generator to operate in parallel with the REC supply with its star point connected to neutral/earth without their approval. This will normally only be given if they are satisfied with the protective multiple earthing arrangements.

These considerations do not concern most asynchronous machines which use the generator as a starter. These are only connected in the star mode at start-up and normally run in the delta configuration.

9.5 Testing

Generator sets should be tested as a complete unit (i.e. with the associated control equipment) for output and performance in accordance with requirements of BS649, BS2613, BS4999 and Recommendation G59/1, as appropriate. Normally the REC will require to witness tests carried out by the installation engineers and a certificate will be issued.

Multiple synchronous generators operating in parallel during standby operation may pose problems of control stability and accordingly will require careful setting up. Further information on the more detailed aspects of standby sets will be found in the Association of British Generating Set Manufacturer's Technical Memorandum TM3.

If synchronous generators which are to operate in parallel are also to be used for standby generation, then 'ad-hoc' approval should be sought from the REC.

KEY POINTS

- All electrical installation work and cable sizing must comply with the relevant statutory requirements. The G59/1 recommendations and ETR 113 are particularly relevant to CHP installations.
- Switchgear and cables for the CHP system should be rated for the requirements.
- The installation must be properly earthed and the CHP unit must have an earthing system that does not depend on the REC.
- Earth electrodes and connections should be in accordance with Electricity Council Engineering Recommendation G12/2 and IEE Wiring Regulations.
- Synchronous generators are operated in star point mode, with the star point connected to the system neutral. In standby operation mode the star point of the generator should be connected to an independent earth.
- Private generators intending to operate in parallel with the mains electricity have a statutory obligation to advise the REC.
- A contribution to engineering costs will generally be required for modifications or additional protection equipment deemed necessary by the REC.
- Normally the REC will require to witness G59/1 tests carried out by the installation engineers.

10. **FUEL SUPPLIES AND INSTALLATION**

10.1 Gas

10.1.1 *Pipework and Sizing*

Generally the arrangements for the gas supply should conform to British Gas Publication IM/17, 'Code of Practice for Natural Gas Fuelled Spark Ignition and Dual Fuel Engines' which should be consulted in conjunction with this document, even when the gas supply is from sources other than British Gas.

The size of the gas supply pipework must be selected to satisfy the specified supply rate and pressure. The nominal British Gas supply of 20-25 mbar (8-10" water gauge) is normally adequate for CHP operation. Typical gas supply pipe sizes for CHP units are given in Table 3.

Table 3 Gas supply pipe sizes

	Machine Size kWe	Supply Pipe Diameter mm I.D.
up to	45	40
	85	50
	155	50
	240	65
	400	80

Pressure losses due to the length of pipework, number of fittings and check meters should be calculated rather than arbitrarily assumed. Installers should consult the engine manufacturer's precise specifications for individual applications. The use of a gas booster may be desirable in some instances: see British Gas Publication IM/16, 'Guidance Notes on the Installation of Gas Pipework, Boosters and Compressors'.

In a building which already uses natural gas as its main boiler fuel, the installation of the CHP unit is likely to cause some overall increase in gas demand, typically 5-10%. This is unlikely to cause problems with the sizing of existing mains supply pipework, but should be checked.

The pipework should be to BS1387, BS21, BS1965 and IM/16, either screwed or welded. It should be pressure tested and purged before commissioning: see British Gas Publication IM/2 and IM/5.

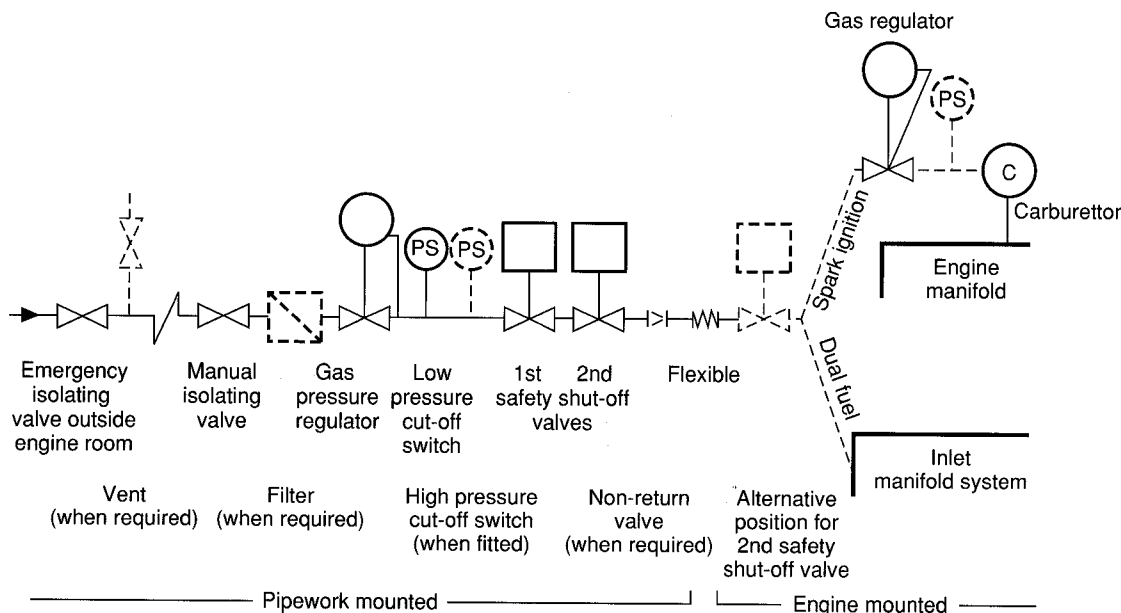
A suitable flexible connection must be installed between the CHP unit and the gas supply. This should preferably be of metal braided construction to BS6501 Part 1. It should be able to withstand a positive pressure of 3.5 bar (50 psi) and also the engine suction, without sustaining damage under fault conditions. It should have screwed or flanged connections and be installed in a position where it will not be weakened by heat from the engine or subjected to tension or mechanical forces. Non-metallic hoses are not permitted under the requirements of the Gas Safety (Installations and Use) Regulations.

Provision should be made for tests of the gas-tightness of the flexible pipe as part of the maintenance schedule (see IM/17 for test details).

If biogas, which may contain significant amounts of water vapour and sulphur compounds, is to be used as a fuel, steps should be taken to ensure that no water, condensed in the gas pipes, runs into the engine. This may require the provision of condensate drains and special flexible pipes.

10.1.2 Valves and Controls

A gas safety shut-off valve (operated by the control system) together with its associated low gas pressure detector and a manual isolating valve should all be rigidly mounted on the supply side of the flexible coupling. The control system's electrically operated shut-off valve(s) should conform to BS5963. See Fig 12 for schematic details of a typical gas train.



Note:
Not all the above equipment is included in the manufacturer's specification as standard equipment.

Fig 12 Typical engine gas control train

The low gas pressure detector should be regularly checked as part of the maintenance schedule. For a normal gas supply of 20 mbar (8" water gauge) it should operate at a pressure of not less than 10 mbar (4" water gauge) and higher for other types of supply. (See IM/17).

Ideally, for engines that run unattended, a 'spit-back' detector should be fitted to detect back-firing in the inlet manifold. This can be achieved by sensing the inlet manifold pressure for high pressure pulses via a high pressure switch fitted to the gas supply pipe. Failure to do this can result in air inlet filters igniting.

10.1.3 Metering

If gas meters are provided on the gas supply to each unit then consumption can be checked regularly. This will allow periodic checks to be made of operating efficiency thus allowing speedier identification of possible faults, or falling efficiency. It is important to correct the meter readings for both temperature and pressure. Under normal circumstances a turbine meter should not be used with reciprocating engines since pressure pulsations could lead to significant over-registration.

10.2 Gas Oil/Diesel Fuel

10.2.1 Fuel Grade

Most diesel engines are designed to run on Class A fuel (DERV) or Class D fuel (Gas Oil) both to BS2869. If the fuel oil to be used is other than Class A or D an analysis should be

submitted to the engine manufacturer for approval. Sulphur dioxide emission may also be increased, resulting in an increase in the required chimney heights as provided for under the 1956 Clean Air Act.

10.2.2 Boiler Room Storage

All fuel oil installations have to comply with local regulations. Most allow for storage of up to 500 litres in one location without special precautions, but in practice the actual capacity of the tank should be based on the size of the CHP unit. As a practical guide, a diesel engine consumes about 0.33 litres of fuel per kilowatt hour at full load but actual figures should be checked with the manufacturer.

The daily service tank should be constructed following BS799 Part 1, and placed as near to the engine as convenient. The bottom of the tank should be level with the fuel inlet of the engine or at least 500 mm above if the engine is not equipped with a fuel pump. A minimum of one hour's operation of the CHP should be possible from the tank.

Fig 13 shows a typical tank installation.

A visual fuel level indicator should be provided. On small tanks a float operated contents gauge should be used while a fail-safe sight gauge could be fitted on larger tanks. Remote indication of fuel contents can be achieved with hydro-static or electrically operated units if required.

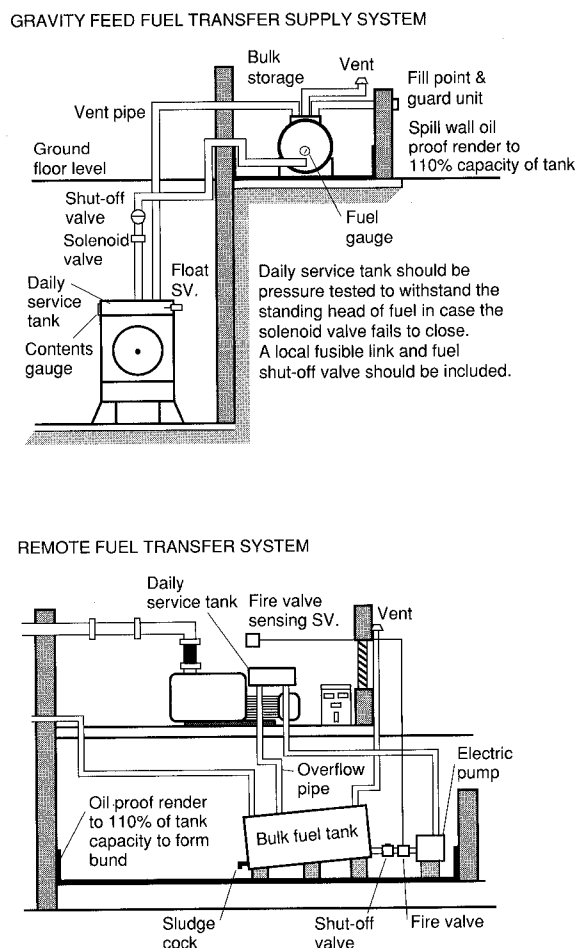


Fig 13 Typical oil storage arrangements

Fuel tanks should *not* be made of galvanised iron as zinc is attacked by fuel oil, and should be positioned so that they are easily accessible for inspection. The fuel outlet should be raised from the bottom of the tank to prevent water and sediment entering the fuel line.

An electric fuel pump will normally be used to fill the daily service tank. This will usually be controlled by a float switch in the service tank. Provision should be made for an overflow pipe back to the bulk tank to allow for failure of this switch. If the daily service tank is gravity fed ensure the bulk storage tank provides an adequate head to overcome strainer and metering resistance, especially in winter when 'waxing' may occur.

The engine fuel-injector spill-back pipe should be returned to the tank which should also have a drain valve and hose connection.

10.2.3 Bulk Storage

External oil tanks should be located in accordance with the recommendations of British Standard Code of Practice 3002. Bulk tanks located inside the building should be housed in an enclosure of fire-resisting construction and have a catch-pit in accordance with CP3002.

The tanks should be manufactured in accordance with BS799, Part 5 and incorporate the following facilities:

- provision for each tank to be isolated for cleaning and repair;
- a vent direct to the atmosphere;
- a visible oil level indicator;
- tanks, piping and other metal work associated with the installation should be electrically continuous with the metal work of the engine unit and earthed in accordance with IEE Regulations.

Bulk storage tanks should have a sludge cock at the lowest point for drawing off sludge and water. The fuel supply should be at least 80 mm above the sludge cock, preferably at the other end of the tank. Precautions should be taken against the ingress of dirt and water into the tank and a mesh filter no coarser than 120 mesh, should be fitted in the draw-off line.

10.2.4 Fire Precautions

Where bulk storage tanks are installed in business premises, the local fire protection requirements usually insist on the fitting of fusible link operated free-fall fuel shut-off valves to the tank outlet pipes and the erection of an oil-tight spill wall around the tank to retain its contents in a controllable area should damage to the tank occur.

KEY POINTS

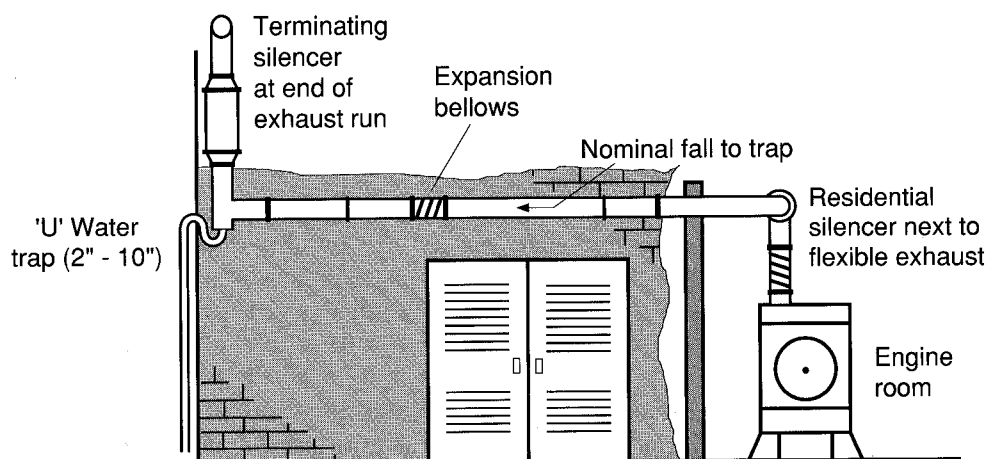
- Arrangements for the gas supply should conform to British Gas Publication IM/17 even when the gas supply is from sources other than British Gas.
- Pipework, valves and flexible connectors must be installed and tested to relevant British Standards and British Gas guidelines.
- The engine gas control system should include low gas pressure detectors together with a spit-back detector.
- Where metering is fitted this should be of the positive displacement type rather than a turbine meter which is affected by the engine pressure pulsations.
- It is a statutory requirement to provide British Gas with 14 days written notice of the intended installation.
- Class D fuel oil is most commonly used for diesel engines and tank installations should comply with all the relevant British Standard requirements.

11. EXHAUST SYSTEMS

An exhaust system must fulfil all of the following requirements:

- disperse the exhaust gases at a safe and aesthetically acceptable position;
- reduce noise levels to an acceptable level;
- be manufactured from materials with an economic life expectancy;
- produce a back pressure within the engine manufacturer's specification;
- must drain all exhaust condensate to the drains provided.

Fig 14 shows a typical exhaust installation.



Note:

- Additional traps for condensate may be needed at engine and/or at silencer.
- Sleeve through wall.

Fig 14 Typical exhaust run

11.1 Point of Discharge

IM/17 sets out the specific requirements for natural gas fuelled engines and the main aspects are detailed below.

It is important to note that exhaust systems must be separately flued and not combined with those from other plant, nor other engines.

The exhaust vent must not be close to any doors, windows or air inlets in order to prevent fumes blowing back into the building, since the engine exhaust contains carbon monoxide and traces of burnt lubricating oil which may have an unpleasant odour. The exhaust should also be well away from noise sensitive areas.

For CHP units running on oil, or other fuels such as biogas which contain sulphur, the height of the exhaust outlet is also subject to the regulations concerning sulphur dioxide emissions in the 1956 Clean Air Act. These regulations are more significant for engines of over 60 kWe. The third edition of the '1956 Clean Air Memorandum on Chimney Heights' published by the Department of the Environment in 1981 gives formulae for exhaust outlet height as a function of rate of sulphur dioxide production, type of district, and with corrections for building effects.

The end of the exhaust pipe should be tilted downward to prevent rainwater entering, but care should be taken to ensure that exhaust gases are not directed on to nearby brickwork which would be corroded and that any acidic condensate that may drip from the exhaust pipe will cause damage to the surfaces below.

11.2 Pipe Sizing and Back Pressure

The diameter of the exhaust pipe required is determined by the necessary length of exhaust run and the maximum back pressure permitted by the engine manufacturer. The back pressure limit may vary considerably from machine to machine; for example, some engines may accept 50 mbar (20" wg), others only 5 mbar (2" wg). The presence of silencers will also increase the back pressure. The pipe and joints should be of sufficient strength to withstand pressures due to backfiring under fault conditions.

An indication of the likely exhaust pipe size for a two silencer system with less than 25 mbar (10" wg) resistance and with no condensing heat exchangers is given in Table 4.

Installers should consult individual engine manufacturer's specifications for precise details of back pressure limits and pipe sizes.

Table 4 Exhaust pipe diameters for a two silencer system

Length of Exhaust Run: Machine Size (kW _e)	Up to 10 m (mm)	Up to 20 m Exhaust Pipe Diameter (mm)	Up to 30 m (mm)
30	65	80	100
45	80	100	125
85	100	100	125
155	125	100	150
240	125	125	150
400	150	150	175

11.3 Materials

11.3.1 Exhausts for Non-Condensing Systems

The mildly acidic water vapour in engine exhaust gases produces near ideal conditions for corrosion. Where the gas temperature is regularly above 100 °C, mild steel pipe to BS1387 can be used. At lower temperature where liquid condensate may be present at certain times, galvanised pipe to BS1387 is more suitable. However mild steel pipework may need replacing, possibly every 5-8 years, depending on actual operating conditions. For longer life, stainless steel pipe can be used, but the sulphur dioxide present in some exhaust gases may cause stress corrosion cracking. Only high quality (and therefore expensive) stainless steels such as the molybdenum stabilised austenitic type AISA 316 can be recommended.

One particular feature of exhaust 'corrosion' is the erosion of pipe bends by high velocity water droplets. Provision should be made for easy replacement of these since some may need replacing as often as every other year. Regular inspection should be made for signs of corrosion in the whole exhaust system.

Hot exhaust pipework should be insulated where it might pose a hazard to personnel or in areas where the radiated heat is undesirable. Particular care should be taken with flexible sections and with pipework adjacent to control equipment, the gas supply, or the air intake. Hot exhaust pipework should be kept clear of all combustible material, such as wooden floors, walls or roofs but where exhaust pipes pass through these, suitable sleeves and air spaces should be provided.

11.3.2 *Condensing Systems*

Where the exhaust gases have been cooled to below 50 °C, suitable plastic pipework can be used, provided the pipework manufacturers approve its use for such purposes. Particular care should be taken in its use indoors due to the CO emission from the engines which could leak into the building if the plastic pipe becomes damaged. Only jointing methods approved for the purpose should be used. A suitable interlock *must* be fitted to shut down the CHP unit if the exhaust temperature rises above a preset maximum determined by the pipe material.

11.3.3 *Use of Existing Flues*

Existing brick chimneys can sometimes offer a convenient solution to the problem of providing exhaust outlets high enough to disperse fumes and noise. However, they must be lined to prevent corrosion of the building fabric.

11.4 *Condensate Drainage*

The degree of drainage and trapping of condensate depends on whether or not condensing operation is intended and also on the length of the exhaust system. If a condensing heat exchanger is used, then almost all of the water vapour in the exhaust gases will be condensed out at that point and very little will be produced further down the system. In a higher temperature system, condensate may be produced anywhere along the exhaust and particularly towards the end where it emerges from the building. Even if condensate is not formed under normal steady working conditions, it will be formed during start-up from cold in winter.

Condensate must be drained from the exhaust system and heat exchangers. If it is not, it may build up in low lying pipe runs producing an increased resistance to flow, or even worse, run back into the engine when it is switched off, causing mechanical damage. Hot heat exchangers and engine parts can be cracked by a sudden back-flow of cold water.

Adequate condensate drainage must also be provided at suitable points in the exhaust system and the pipe runs arranged with adequate fall to allow the condensate to run to drain. These drains must have water traps to prevent exhaust fumes from being released. To ensure the water trap is maintained at a normal depth it may be necessary to provide level control via a ballcock arrangement.

Where condensing heat exchangers are used, a large diameter drain should be run into a water filled tank acting as a trap. The condensate then overflows from the tank and is piped to a normal storm or foul water drain. In order to function as a trap the tank depth must be greater than the back pressure of the exhaust gas. As an example, if the exhaust system produces a back pressure of 50 mbar (20" wg) then the tank should be at least 500 mm deep.

It may be necessary to raise the CHP unit slightly above floor level in order to get sufficient height for proper condensate drainage.

Because the condensate flow rates are relatively small, pipework can easily block up from an emulsion of burnt lubricating oil, carbon and debris etc., and which initially adheres to the exhaust walls, accumulates and then becomes detached. Pipes should thus be either flexible to permit cleaning, or of sufficient diameter, i.e. 15 mm or more, to prevent clogging. The drains should be clearly visible so that blockages can be quickly dealt with.

Hollow reactive type silencers are particularly prone to filling up with condensate and may require more than one drain. Ideally they should be mounted vertically to simplify matters, but installers should consult the manufacturer's instructions with regard to mounting and drainage requirements.

Exhaust condensate is acidic and thus condensate pipework should preferably not be made of copper. Tanks and pipes should be of plastic or galvanised steel. The condensate should not be allowed to run across concrete flooring as it will discolour and corrode it. For large engines it may be necessary to discharge into drains that have sufficient water flow to dilute and cool the condensate.

11.5 Silencers

As with automotive vehicle applications, there are two types of silencer: the reactive hollow box type and the straight through absorption type. The reactive type relies on the acoustic capacitance of the hollow silencer chamber and the inductance of the long exhaust pipe to smooth out exhaust gas pulses. Given the relatively long pipe runs in most installations, this can be very effective at reducing low frequency noise in the range 50-200 Hz.

The absorption type consists of a chamber filled with sound absorbent material. It is not as effective as the reactive type at reducing low frequency noise, but is superior at higher frequencies in the range 500-4,000 Hz where the ear is most sensitive.

For the majority of applications one reactive silencer is likely to be sufficient. This should be placed close to the engine and, if extra noise reduction is needed, then an additional absorption silencer should be placed at the far outlet end of the exhaust, which preferably should have a tail pipe of at least ten pipe diameters in length. For short exhaust runs, the two silencers should be at least ten pipe diameters apart.

KEY POINTS

- Exhausts for natural gas fuelled engines should comply with the requirements of British Gas Publication IM/17. In particular engine exhaust systems must be separately flued.
- Exhausts should be sized in accordance with the necessary length and engine manufacturer's back pressure limits and comply with the Clean Air Act.
- Galvanised or stainless steel pipework should generally be used but plastic materials may be suitable, particularly with condensing systems.
- Condensate drainage must be provided for the exhaust system and associated heat exchangers. Both drains and traps should be clearly visible so that water levels and/or blockages can be dealt with quickly.
- A single reactive silencer should be located close to the engine and if further noise reduction is needed an additional absorption silencer should be placed towards the far outlet of the exhaust.

PART D: COMMISSIONING AND OPERATION

12 CONTRACTUAL TERMS

Different organisations will have their own laid-down procedures governing the letting of contracts. These will vary from simple purchase orders to formal specification and tendering documents culminating in signed and witnessed contracts. It is suggested that CHP is treated no differently from other projects of similar capital cost, but with the addition of performance guarantees.

12.1 Performance

The contract documentation should state in clear terms what performance guarantees are expected in respect of the CHP unit for the following key performance criteria:

- minimum average electrical output when measured at the generator metering point, over each of the following operating periods; 30 minutes; 500 hours; 5,000 hours; 25,000 hours;
- the maximum fuel consumption under each of the above conditions;
- the minimum heat output under each of the above conditions;
- routine maintenance time required (if any) per day/week of the site/plant operator;
- maximum total maintenance costs for the CHP system including all parts, labour and travel and covering 25,000 hours operation. Expressed as pence per kWh generated.

Also if the CHP has been selected and/or sized by the supplier; the anticipated minimum hours run per year or alternatively, the minimum net savings benefit (£/y) and the basis of the calculations.

The extent and period of the warranty should also be explicitly detailed. Other important factors are; anticipated system noise levels and, exhaust gas emissions and temperatures. Where necessary, supporting documentation should be requested to give credence to the performance guarantees. The user should satisfy himself of the supplier's ability to provide after sales support at reasonable prices.

12.1.1 *Terms of Payment*

Realistic Terms of Payment which should be agreed between the end user and the supplier/installer, could comprise:

- 10% on placing order;
- 30% on delivery, undamaged, all CHP units;
- 50% following final commissioning;
- 10% at end of warranty period, providing agreed performance is achieved.

12.1.2 *Acceptance of Terms*

A supplier/installer with confidence in the project and the plant should be willing to agree to performance guarantees linked to terms of payment. In addition the supplier should be willing to provide references of existing installations which if desired can be visited after a letter of intent to purchase is issued.

12.1.3 *Price*

The end user should ensure that there are no hidden additional costs involved: for example if a crane is needed to off-load and position the CHP unit, make sure this is included in the total

price and similarly so any builder's work and other 'making good'. Finally, any spare parts which the equipment supplier expects the operator to hold on his behalf, should be costed into the price, or supplied 'on consignment' FOC to the operator.

The cost of any declarations, tests, full commissioning and documentation, including an operating manual and system drawings, should also be included. Where appropriate operation and maintenance instruction should also be included.

KEY POINTS

- Contract arrangements for CHP should follow the organisation's standard practice but with the inclusion of performance guarantees and costs associated with maintenance requirements.
- Terms of payment should be negotiated between the end user and the supplier.
- The costs of tests and full commissioning should be included as well as the supply of operating manuals, drawings and associated documentation.

13 MAINTENANCE AND FINANCE OPTIONS

13.1 Maintenance Contracts

CHP equipment suppliers offer a range of maintenance contracts to ensure reliable operation of the plant.

Remote plant computer monitoring generally forms the basis for determining optimum service intervals and to provide preventative maintenance.

The options available vary with manufacturers, but it is also possible to obtain performance and availability guarantees linked to the maintenance contract terms.

13.1.1 *Finance Options*

CHP suppliers can generally offer a range of finance options other than outright purchase. These include leasing as well as packages specific to CHP systems.

The most frequently used type of finance option is based on supply, installation and commissioning of the CHP package at no cost. Fuel is purchased as normal at the site and the client pays for electricity generated by the CHP unit. The electricity cost agreed is such that there is a net benefit to the site compared with electricity purchased from the REC. The magnitude of the savings so obtained will be less than with outright purchase. Maintenance costs are included in the package and cover the lifetime of the agreement, typically 7 to 10 years.

Shorter term agreements are also available where part of the costs are shared, for example the customer pays the installation cost with the CHP unit financed by the supplier.

The contractual terms should be studied carefully, in particular the basis for review of the cost of the electricity generated as well as performance guarantees for availability and output.

KEY POINTS

- Maintenance contracts are available linked to performance and availability guarantees.
- Finance options are available from many suppliers based on supply and installation of the package at no cost with a reduced level of savings.

14 COMMISSIONING

Every CHP unit manufacturer should be able to demonstrate that he has a thorough commissioning procedure covering such areas as:

- G59/1 compliance;
- electrical and mechanical safety checks;
- performance checks; thermal and electrical output;
- system control and setting up;
- combustion testing.

These items should ideally be verified/repeated after an initial settling down period of 500 hours and a certificate obtained from the commissioning engineer, setting out the actual control settings and performance achieved. 'Factory-set' commissioning will assist in reducing installation costs but, as the site conditions will influence setting up, this is not a substitute for full site commissioning.

Part of the commissioning procedure should include instruction of the users in the correct operation and any routine maintenance requirements of the CHP system which the user is expected to carry out.

A CHP system should not be accepted as 'handed over' until the user is satisfied that all contractual terms have been fully met.

Of paramount importance is a clear demonstration to the user that the CHP unit(s) will shut down under fault conditions, and should be demonstrated by simulated fault wherever possible rather than by alteration of the settings. This is a Factories Act requirement and is the overriding responsibility of the operator.

KEY POINTS

- Ensure commissioning and training is included in the offer price.
- Ensure the plant is fully commissioned before it is accepted as 'handed over' to the user.
- Ensure G59/1 and any other statutory requirements/tests have been satisfactorily completed.
- Safety shutdown should be demonstrated to the operator/user as part of the handover procedure.

15 OPERATING THE CHP SYSTEM

15.1 Operation of CHP with Existing Boiler Plant

The importance of carefully assessing the building's heating system (i.e. the CHP heat sink) in order to ensure satisfactory integration of the CHP unit has been highlighted in Part B of this guide. Equally, the implementation of an effective CHP and boiler plant control and operating strategy is necessary in order to ensure proper and cost effective operation of the CHP unit.

The conventional method of operating a heating system is to control the boiler flow temperature and leave the return temperature to float upwards under reducing load conditions. Thus under design conditions, maximum heat demand results in the lowest return temperature and when reduced load conditions apply, the return temperature increases, sometimes to close to the flow temperature.

With CHP systems, the conventional control strategy should be reversed and the system regulated by controlling the return temperature, leaving the boiler flow temperature to float according to demand. In this way the flow temperature rises within the limit of the permitted maximum, to ensure the return temperature is maintained at, or rises to, but does not exceed, the 70-80 °C maximum inlet temperature generally required by the CHP unit.

There is an additional benefit from this method of control in that heat losses from both distribution and boiler plant are reduced as a result of the lower temperatures in use. In the course of time this method of control may become the accepted norm for energy efficient installations.

Alterations to the system are neither difficult nor expensive to achieve. A new sensor and pocket is required on the return and a sequencer must be wired-in, in the conventional fashion but with the CHP as lead boiler.

15.1.1 *Building Energy Management Systems (BEMS)*

If the heating services are controlled by BEMS, then it may be possible to achieve return water temperature control by the simple addition of a return sensor. BEMS do offer great flexibility in determining ON/OFF periods and for fine tuning of optimum run times to maximise savings.

15.2 Operational Procedures

To achieve successful cost saving operation of the CHP following commissioning will, as stated in Section 14, require an initial settling down period and careful observation of how it is actually performing.

Maximum achievement of cost savings benefits means ensuring that the CHP runs in preference to the boiler plant whenever it is economic. Usually this means not operating at either night time or during periods of low electrical load and/or the availability of cheaper purchased electricity. Thus an element of trial and error may be required to establish the optimum time clock settings which will control the CHP's operating periods.

System temperature and control valve settings may also require fine tuning for optimum determination of settings.

It is suggested that this 'fine-tuning' and optimisation process is carried out, if possible, in conjunction with the person who undertook the feasibility study, as that person should be the most knowledgeable with regard to the actual requirements and 'modus operandum' of the system prior to installation of the CHP. It should also ensure the intended strategy is fully understood by the operator.

Day-to-day operational requirements should be relatively minor once successful operation of the plant has been achieved and should be confined to routine checks on coolant and oil levels etc. (as laid down in the manufacturer's schedule), and the occasional reset of the plant if and when the unit trips out.

What is most important is to ensure that the operator is fully acquainted with his responsibilities and has been shown what is expected of him.

A log book should be instigated at the outset and all activity relating to the CHP and boiler plant recorded. This greatly facilitates keeping track of what is happening to the plant and is an invaluable service aid when investigating any intermittent problems which may occur.

A simple monitoring sheet should also be devised on which the essential data required for evaluation of benefits can be recorded. This should be completed weekly and sent for analysis to the person ultimately in charge of the plant. An example of a monitoring sheet is included in Appendix 4. With the routine use of remote computer monitoring, this data would also be provided by the CHP equipment supplier.

15.3 Performance Monitoring

15.3.1 Instrumentation Requirements

CHP is generally installed to save money. Whether it does or does not do so can only be established by monitoring the performance of the unit.

To achieve this the minimum instrumentation installed should be:

- electricity generated meter (kWh);
- hours run meter (h);
- gas consumption meter (ft³ or m³).

Further useful performance indicators are:

- total hours required (h);
- hours failed and/or out of service (h);
- number of stops and starts the unit makes (to identify cycling or repetitive faults).

It is important, for proper operation of the metering, to ensure that it is installed correctly. This applies particularly to the flow metering and temperature measurement. The manufacturer's requirements should be carefully adhered to.

If a condensing economiser is fitted and money is available without jeopardising the project's viability the addition of a water meter to the circuit is advantageous. From this, water flow rates can be measured and hence the heat recovered can be determined when flow and return temperatures are measured.

15.3.2 Performance Parameters

With the minimum instrumentation installed, the basic performance can be ascertained and hence the savings achievement established provided the following important parameters are logged and examined regularly:

- hours run in period;
- electricity generated in period;
- gas consumption in period;
- heat output if available.

From this data the following performance parameters should be determined and compared with the manufacturer's figures given in the performance guarantees.

$$\begin{aligned}
 \text{Average Output (kWe):} & \quad \frac{\text{Electricity Generated (kWh)}}{\text{Hours Run}} \\
 \text{Average Gas Input (kWg):} & \quad \text{either} \quad \frac{\text{Gas Consumption (kWh)}}{\text{Hours Run}} \\
 & \quad \text{or} \quad \frac{\text{Vol (ft}^3\text{)} \times \text{C.V of gas (Btu/ft}^3\text{)}^{*1} \times \text{Correction Factor}^{*2}}{3,412^{*3} \times \text{Hours Run}} \\
 \text{Average Heat Output (kWh):} & \quad \frac{\text{Heat Supplied (kWh)}}{\text{Hours Run}}
 \end{aligned}$$

The way in which these figures vary with time can be observed and any change in performance identified and quickly rectified.

15.3.3 Savings Achieved

Assuming all electricity generated displaces daytime units at flat rate value the savings can be calculated thus: $\text{Net Benefit} = \text{Savings} - \text{Costs}$

$$\begin{aligned}
 \text{Electricity Savings:} & \quad = \quad \frac{\text{Period kWh generated} \times \text{value in p/kWh}}{100} \\
 (\text{£Es}) &
 \end{aligned}$$

$$\begin{aligned}
 \text{Cost due to extra gas}^{*4} & \quad = \quad (\text{kWg} - \frac{\text{kWh} \times 100}{\% \text{ boiler efficiency}}^{*5}) \times \text{hours run} \times \frac{\text{gas cost in p/th}}{29.31 \times 100} \\
 (\text{£Xg}) &
 \end{aligned}$$

$$\begin{aligned}
 \text{Maintenance Cost:} & \quad = \quad \text{kWh generated in period} \times \frac{\text{maintenance cost in p/kWh}}{100} \\
 (\text{£Mc}) &
 \end{aligned}$$

$$\text{Therefore Net Benefit(£):} = \text{£Es} - (\text{£Xg} + \text{£Mc})$$

Where a Seasonal Time of Day electricity tariff applies a more detailed calculation of the electricity savings will be necessary, based on the daily pattern of site electrical demand: see Section 7.2.

*1 Circa 1,030 for natural gas.

*2 Gas meter reading correction factor for gas pressure and temperature.

*3 1 kWh = 3,412 Btu; 29.31 kWh = 100,000 Btu = 1 therm.

*4 The extra gas referred to here is that due to the lower heat generation efficiency of a CHP unit when compared to that of a boiler and therefore represents a charge against savings.

*5 Boiler efficiency obtained from tests or previous table in Part B Section 4.

15.4 Maintenance Requirements

CHP units are relatively complex compared to boilers and require more extensive maintenance. The following is a guide to a typical maintenance schedule for small CHP units, included in order to illustrate the general servicing that must be undertaken by whoever accepts this responsibility. Maintenance requirements vary with the size and type of CHP unit.

Many installations are now computer controlled, with routine checking of key parameters. In practice, this means that day-to-day maintenance is eliminated. Regular servicing is still required every 500 hours or so. The figures presented here are purely illustrative. Manufacturers' recommendations with regard to maintenance should always be followed.

<u>MAINTENANCE</u>	<u>PARTS</u>	<u>LABOUR</u>
Daily (or 24 hours): <ul style="list-style-type: none"> - Check oil level - Check coolant level 		5 mins
Weekly (or 200 hours): <ul style="list-style-type: none"> - Check belt tension - Check battery level - Clean crankcase breather 		15 mins
Monthly (or 500 hours): <ul style="list-style-type: none"> - Replace spark plugs - Change engine oil - Change filters - Check valve clearance - Lubricate generator bearings - Lubricate linkages - Test safety controls 	6 off 25 litres 2 filters	4 hours
2-Monthly (or 1,000 hours): <ul style="list-style-type: none"> - Check general security of all items - Lubricate starter bearings - Change air filter 	1 air filter	1.5 hours
Annually (or 8,000 hours): <ul style="list-style-type: none"> - Check engine/generator alignment - Check cylinder compressions - Check engine thermostat operations - Check water pump bearings - Replace belts - Flush and refill cooling system - Change carb. diaphragms 	1 set belts Anti-freeze 2 x diaphragms	5 hours
2-Yearly (or 15,000 hours): <ul style="list-style-type: none"> - Carry out top overhaul - Replace water hoses 	1 set 'Top over-haul' gaskets 1 set hoses	20 hours
3 Yearly (or 25,000 hours): <ul style="list-style-type: none"> - Strip engine and overhaul as necessary 		40 hours

Manufacturers can provide a range of maintenance agreements from all-inclusive, with or without emergency call-out, to major servicing only, with lubrication servicing provided by a local contractor/in-house. The most suitable agreement will depend on a number of factors including resources at the site and distance from the manufacturer's/agent's premises. Maintenance and condition monitoring is a key aspect of achieving performance and savings and it is generally preferable to arrange comprehensive maintenance contracts with the equipment supplier. These options should have been assessed in detail during the feasibility stage and actual responsibilities and costs determined from discussion with the manufacturer: see Part B of this guide.

15.4.1 Combustion Analysis

Internal combustion engines, unlike boilers, are very sensitive to ignition, mixture and timing settings. In particular, if these deviate from the correct settings the power output will fall. The engine governor will respond (if it can) and the exhaust gas composition will change, often dramatically and for very small changes in optimum settings. This can result in a large variation in CO (carbon monoxide) levels in the exhaust gases, from around 3,500 ppm to perhaps 25,000 ppm (2.5%). Combustion performance will depend both on engine type and the particular engine itself but a typical combustion analysis should be about 1% O₂ (oxygen) allied to less than 5,000 ppm (0.5%) CO. Fig 15 shows the relationship between CO, oxygen and power output as measured on a small CHP unit.

Not only is CO in excessive quantities undesirable, it is very wasteful of fuel. Accordingly as a matter of good practice whenever the engine is serviced, the CO levels should be checked and the 'as left' conditions recorded in the log book, along with the O₂ level and exhaust gas temperature at the system exit.

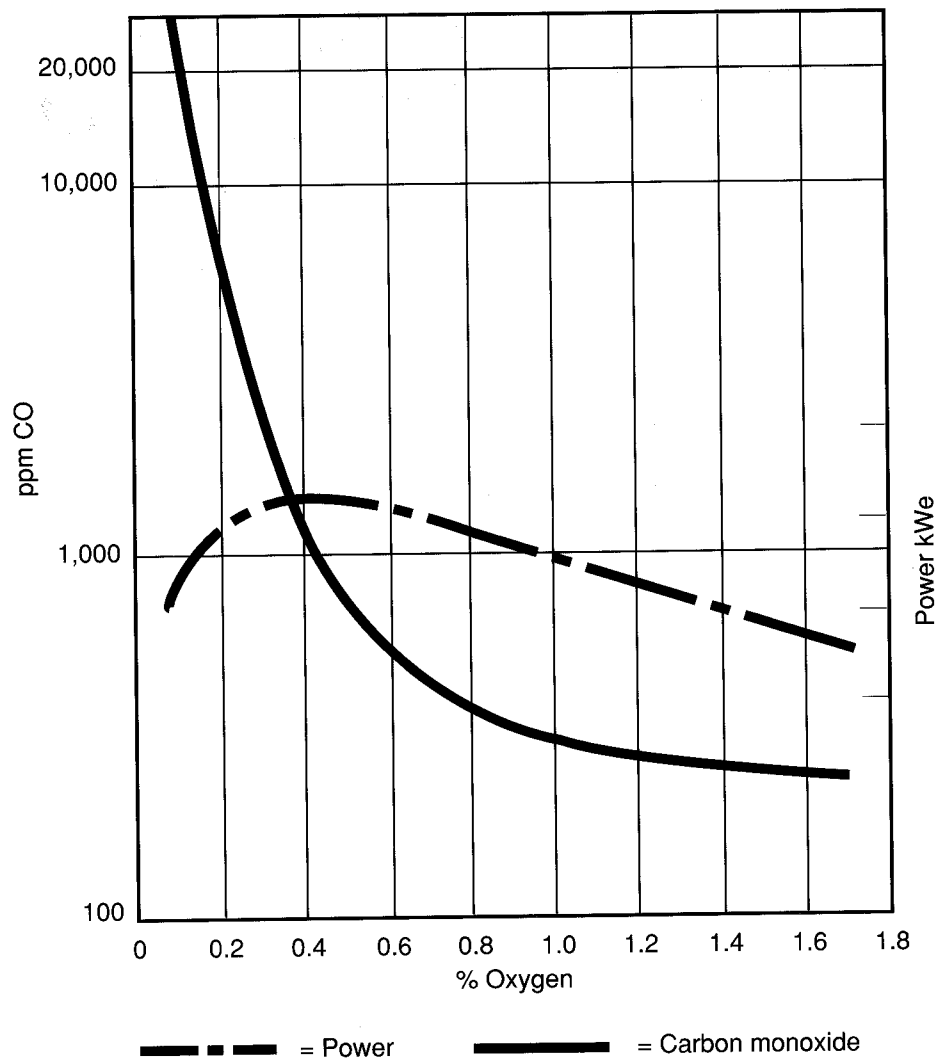


Fig 15 Exhaust gas: oxygen/carbon monoxide/engine power relationship

KEY POINTS

- As well as the implementation of an effective CHP and boiler plant control system it is essential that an operating strategy is established to ensure the optimum running of the CHP system.
- A particularly effective control strategy for CHP systems is based on regulating the return header temperature rather than the conventional method based on flow temperature.
- Once satisfactory operation of the entire plant has been achieved, day-to-day operational requirements should be relatively minor.
- Savings can be calculated through regular monitoring of the CHP unit by metering gas consumption, electrical and heat output as well as operational hours.
- It is generally preferable to arrange comprehensive maintenance contracts with equipment suppliers, particularly if they incorporate performance guarantees.

APPENDIX 1

GLOSSARY OF TERMS

Building Energy Management System (BEMS)	- The modern way to control building services. Consists of a computerised controller and suitable outstations to connect to the boiler, valves, temperature sensors etc. Can add considerable sophistication to control methods and eliminate timeclocks and sequencers.
Conversion Efficiencies	- The way of expressing the proportion of the energy or fuel input which is usefully converted to heat or power, using either the gross or net CV of the fuel, according to custom. Net CV gives higher apparent efficiencies than gross CV.
Demand Profile Recorder (DPR)	- An instrument used to record over consecutive periods, the demand for electricity. Usually uses non-intrusive probes. Can be hired. Enables profiles of electricity consumption to be obtained easily.
Diesel Engine	- Takes its name from the famous German engineer Rudolf Diesel. Operates on the diesel (constant pressure) cycle, igniting the fuel, which is admitted after compression. Has a higher mechanical energy conversion efficiency than the gas engine by virtue of the higher compression ratios possible because the fuel is admitted after compression thereby eliminating pre-ignition.
Diverter Valve	- A motorised 3-way valve installed in a heating system and which diverts the water flow into the return and so provides a constant volume flow.
Ebullient Cooling	- <i>In-situ</i> boiling-off of the cooling liquid, sometimes under pressure.
Event Recorder	- Derived from the Tachograph 'Spy in the Cab'. It is used to register, against real time, the occurrence of an event i.e. the firing of a boiler so enabling hour by hour profiles of heat demand to be assessed. Can be hired.
Excitation Current	- The excitation current is the controlling current in the primary winding of the generator.
Gas Oil	- A distillate fuel oil (Class D), similar in characteristics to diesel oil (Class A) and having a maximum viscosity of 5.5 cSt at 40 °C.
Gross CV	- The UK historically expresses calorific values (CV) in gross terms, i.e. the 'higher value' whereas the European continent tends to use 'net CV' or 'lower value'.
kWe	- Kilowatt electrical. The standard way of expressing the size (output) of a CHP unit.

Latent Heat	- The main ingredient of natural gas is methane, chemical formula CH_4 . When burned, the hydrogen combines with oxygen from the air to form water (H_2O) which is emitted as steam, condensing as water when cooled and giving up its latent heat.
Maximum Demand	- Otherwise known as 'MD'. This is the electricity supply industry standard way of expressing the highest rate of consumption. It is calculated from the measured highest consumption of kWh, usually in consecutive half hour periods commencing when the electricity meters are read and the 'MD' is reset to zero. It does not necessarily reflect the actual highest instantaneous demand of the site.
Mixing Valve	- A motorised valve, generally 3-port, in which two streams of water at different temperatures are blended together to produce water at an intermediate temperature.
Sankey Diagram	- The energy industry standard for showing the energy flows of a process or site. Can be simple or complex according to information available.
Shell and Tube Heat Exchanger	- A commonly encountered type of heat exchanger consisting of a steel shell containing a nest of tubes which can be steel or copper or other suitable material and able to stand high pressure.
Spark Ignition Engine	- An engine which utilises an electrical spark to ignite the compressed air/fuel mixture. Usually operates on the Otto (constant volume) cycle and has mechanical energy conversion efficiency of 24-35%.
Star Delta Starter	- Motor starter which connects the windings firstly in Star format (Δ) and then Delta (Δ) in order to limit starting currents.
Stationary Engine	- An engine in which the power output is not used to transport the engine itself and hence the power/weight ratio is unimportant.
Weathered Compensated Control	- Means of regulating the heat emission from radiators etc., according to changes in the weather, generally by reducing system flow/return temperatures. Provides constant volume flow in the heating unit but not generally to the boiler plant.

APPENDIX 2

REFERENCES

A2.1 Electrical

16th Edition of the IEE Wiring Regulations (Regulations for Electrical Installations).

Electricity Association Engineering Recommendation G59/1, 'Recommendations for the Connection of Embedded Generation Plant to the Regional Electricity Company's Distribution System', 1991*.

Electricity Association Engineering Recommendations G5/3 'Limits for Harmonics in the UK Electricity Supply System', 1976.

Electricity Association Engineering Recommendations G12/2 'National Code of Practice on the Application of Protective Multiple Earthing to Low Voltage Networks', 1982.

Guidance Note PM53 from the Health and Safety Executive 'Emergency Private Generation - Electrical safety'.

Electricity Association Engineering Recommendation P28, 'Planning Limits for Voltage Fluctuation Caused by Individual Commercial and Domestic Equipment in the UK', 1989.

Association of British Generating Set Manufacturers, Technical Memorandum TM3, 'Code of Practice for Designers, Installers and Users of Generating Sets', 1985.

Electricity Act 1989.

Statutory Instrument No. 136 - Electricity, 1984.

A2.2 Gas

British Gas Publication IM/2, 'Purging Procedures for Non Domestic Gas Installations', 1989.

British Gas Publication IM/5, 'Soundness Testing Procedures for Industrial and Commercial Gas Installations', 1989

British Gas Publication IM/16, 'Guidance Notes on the installation of Gas Pipework, Boosters and Compressors in Customers' Premises', 1989.

British Gas Publication IM/17, 'Code of Practice for Natural Gas Fuelled Spark Ignition and Dual Fuel Engines', 1986.

British Gas Publication IM/21, 'Guidance Notes for Architects, Builders, Consultants etc. on the Gas Safety (Installation and Use) Regulations, 1984.

H.M. Government Gas Act, 1986.

Gas Safety (Installation and Use) Regulations, 1984.

* G59 still in force at time of going to print.

A2.3 British Standards

BS21	Pipe threads for pressure tight joints.
BS89	Electrical indicating instruments.
BS159	Busbars and busbar connections.
BS162	Electrical power switchgear & associated apparatus.
BS417	Galvanised mild steel cisterns.
BS440	Stationary batteries for general electrical purposes.
BS649	Diesel engines.
BS764	Automatic change-over contactors.
BS775	Contactors
BS799	Oil-burning equipment.
BS822	Terminal markings for electrical machinery.
BS1387	Steel tubes suitable for screwing to BS21.
BS1649	Guards for shaft couplings.
BS1710	Identification of pipelines.
BS1869	Fuel oil for oil engines.
BS1965	Pipe fittings for pressure purposes.
BS2613	Electrical performance of rotating machines.
BS2709	Electrical performance of semi-conductor rectifiers.
BS2771	Electrical equipment for machine tools.
BS3535	Safety isolating transformers.
BS3926	Use and maintenance of engine coolant solutions.
BS3938	Current transformers.
BS3941	Voltage transformers.
BS4553	PVC insulated cables with copper conductors.
BS4959	Corrosion and scale prevention in engine cooling water systems.
BS4999	General requirements for rotating electrical machines.
BS5117	Test methods for corrosion inhibition performance of anti-freeze solutions.
BS5467	Armoured cables with thermosetting insulation.
BS5963	Electrically operated automatic gas shut-off valves.
BS6004	PVC insulated non-armoured cables.
BS6007	Rubber insulated cables.
BS6231	PVC insulated cables for switchgear and control gear wiring.
BS6346	PVC insulated cables for electricity supply.
BS6480	Impregnated paper-insulated cables.
BS6480	Installation of gas-fired boilers 60 kW-2 MW.

A2.4 Miscellaneous

Codes of Practice (issued by BSI):

- CP1008; Maintenance of electrical switchgear.
- CP3003; Oil firing.

Department of the Environment '1956 Clean Air Act Memorandum on Chimney Heights'.

A2.5 Equipment and CHP Suppliers

The following manufacturers and suppliers are acknowledged for their assistance in supplying material for, and commenting on, this guide.

- Applied Energy Systems Ltd. (Now SPP Energy Ltd.)
- Biklim SpA Totem Division.
- Combined Power Systems Ltd.
- Dorman Diesels Ltd.
- Dresser Industries Inc.
- Holec Ltd. (Now Nedalo (UK) Ltd.)
- Jenbacher Werke AG
- KFS Mini Power Stations Ltd.
- Petbow Ltd.
- Tudor Mechanical & Electrical Services Ltd.
- Watermota Limited. (Now Cogen Systems Ltd.)

The above list is not exhaustive of companies involved in CHP. Up-to-date details of all organisations, for those with further interest, may be obtained from ETSU, or from:

Combined Heat and Power Association (CHPA)

3rd Floor
35-37 Grosvenor Gardens
London
SW1W 0BS

Tel: 0171 828 4077
Fax: 0171 828 0310

A2.6 Regulatory Bodies

Advice and information concerning the operation of Electricity Supply Industry can be obtained from:

England & Wales: **Office of Electricity Regulation (OFFER)**

Hagley House
Hagley Road
Edgbaston
Birmingham B16 8QG
Tel: 0121 456 2100

Northern Ireland:

Brookmount Buildings
44-46 Fountain Street
Belfast BT1 5EE
Tel: 01223 311575

Scotland:

48 St Vincent Street
Glasgow G2 5TS
Tel: 0141 248 5917

Details of independent gas suppliers and other information concerning the Gas Supply Industry can be obtained from:

Office of Gas Supply (OFGAS)

Stockley House
130 Wilton Road
London SW1V 1LQ
Tel: 0171 828 0898

APPENDIX 3

EVALUATION OF SAVINGS' BENEFIT

A. DETERMINING THE SIZE OF A CHP UNIT

Most equipment suppliers and consultants now use computer programs to determine the ideal size of CHP unit for a given location. This enables a quick assessment of the effect of small changes in any of the assumptions made (i.e. sensitivity analysis). The program will generally select the most appropriate unit on the basis of the shortest payback, though other criteria may be used.

A quick first assessment can, however, be made by reference to monthly fuel and electricity bills. To achieve sufficient annual operation and an acceptable payback normally requires year round operation. CHP plant will therefore typically be sized on the basis of the average summer heating load. The method for estimating the CHP size is outlined below.

The gas consumption used should exclude catering usage or other non-heating applications. If this cannot be deduced directly from the bills an assessment of non-heating usage must be made and deducted from the total.

For year round base load operation:

Hourly useful heat (HL), averaged over the 'low' or summer months is:

$$HL \text{ (kW)} = 29.31 * \frac{(G_{\text{June}} + G_{\text{July}} + G_{\text{Aug}}) \times 0.75}{(92 \times Hh)}$$

where G is gas consumption in therms (taken from gas bill) and boiler efficiency is assumed to be 75%. Hh is the daily operating hours.

If the number of days in the billed three-month period is known precisely, then that figure should be used in preference to the 92 days used in the formula. If the number of hours per day that the boiler is operated is not known, then it is suggested that 15 hours should be used in the formula for Hh .

For a site with heating and DHW gas consumptions of 2,700, 3,000 and 2,500 therms in the respective months of June, July and August, an assumed boiler efficiency of 75%, and 15 hours/day use, the above example shows a useful heat requirement of 132 kW.

In a similar way the average daytime 'low' electricity demand (EL) can be established:

$$EL \text{ (kW)} = \frac{(E_{\text{June}} + E_{\text{July}} + E_{\text{Aug}}) \times F}{(92 \times 17)}$$

where E is the electricity consumption, excluding nights, in kWh and F is the utilisation factor of 1.0 if day and night metering is installed. For flat rate metering the average daily consumption should be used with F taken as 0.85 to estimate the day/night split in electricity demand.

For the same site previously used to illustrate the heat requirement 'Night' metering is in being so F is 1.0, and the corresponding electricity 'low' months' consumptions were 36,800, 35,000 and 38,200 kWhs and therefore EL is 71 kW.

A CHP unit with an electrical output not exceeding 71 kWe and a thermal output not exceeding 132 kWth should be selected for this site.

$$* 1 \text{ Therm} = 29.31 \text{ kWh} = 100,000 \text{ Btu.}$$

B. EVALUATION OF SAVINGS BENEFIT

Small scale CHP plant typically has a heat:power ratio between 1.5:1 and 2:1. Using the above figures a suitable CHP size for this site would have an electrical output of around 70 kWe and a thermal output of 130 kWth. Manufacturers' specifications should be checked to find the most appropriately sized unit. Allowing for 5 days out of service per year, the potential hours of use of the unit are $(365 - 5) \times 17 = 6,120$. Consider the CHP unit has the following performance and operating parameters:

- electrical output 70 kWe
- heat output 130 kW
- fuel input 250 kW
- average daytime electricity unit price 5.5p/kWh
- gas price 35 p/therm
- boiler efficiency 75%
- maintenance 0.7p/kWh of electricity generated

			p/hour	total p/hour
SAVINGS:				
Electricity	70×5.5	=	385	
Boiler fuel	$\frac{130}{0.75} \times \frac{35}{29.31}$	=	<u>207</u> 592	592
COSTS:				
CHP Gas	$250 \times \frac{35}{29.31}$	=	299	
Maintenance	0.7×70	=	<u>49</u> 348	<u>348</u>
NET BENEFIT				244 p/hour

The saving is thus £2.44 for every hour of CHP operation. It can be seen that maximising savings requires maximising the hours of operation (subject to there being a demand for heat and electricity). If the maximum potential of 6,120 hours is achieved, annual savings will be:

$$6,120 \times £2.44 = £14,933/\text{year}.$$

A 70 kWe would cost approximately £45,000 to install. The simple payback on this installation is therefore three years. The above calculation is based on typical costs prevalent in 1992. Potential users should establish actual costs, which will vary from site to site.

APPENDIX 4**EXAMPLE OF A MONTHLY CUSTOMER REPORT**

Unit No: 80
 Max. available hrs/day: 17.0

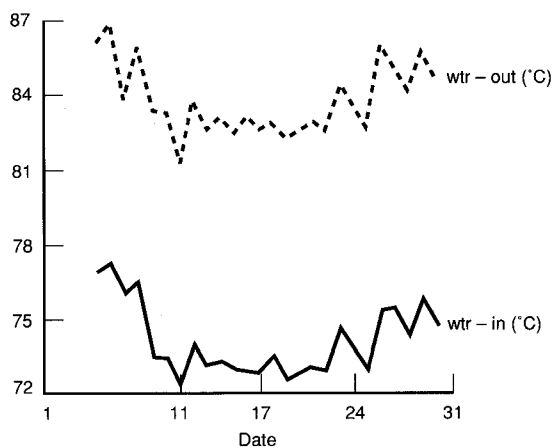
Performance in Month

Hours run: 470	kWh elec. (day): 62297	kWh elec. (night): 0
cu ft gas: NA	kWh heat: NA	
utilisation: 92%	availability: 95%	

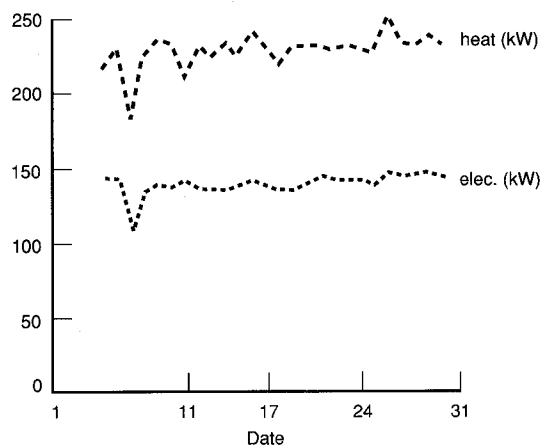
Average Daily Performance in Month

Hours run: 15.7	kW elec. (day): 133	kW elec. (night): 0
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SITE REPRESENTATIVE HEAT DEMAND PROFILE



CHP OPERATING PROFILE

**Stoppages: (Based on 30 Days Data)**

<u>Reason for Stoppage</u>	<u>No. of Logs</u>	<u>Hours</u>
External on/off	5	0.6
Emergency stop	39	23.2
Gas pressure switch	18	15.6
Trip sense	4	3.2
Low exhaust temp.	1	0.1
Cannot start	15	<u>0.7</u>
		43.4